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Human Population Exposures to Coke-Oven Atmospheric Emissions

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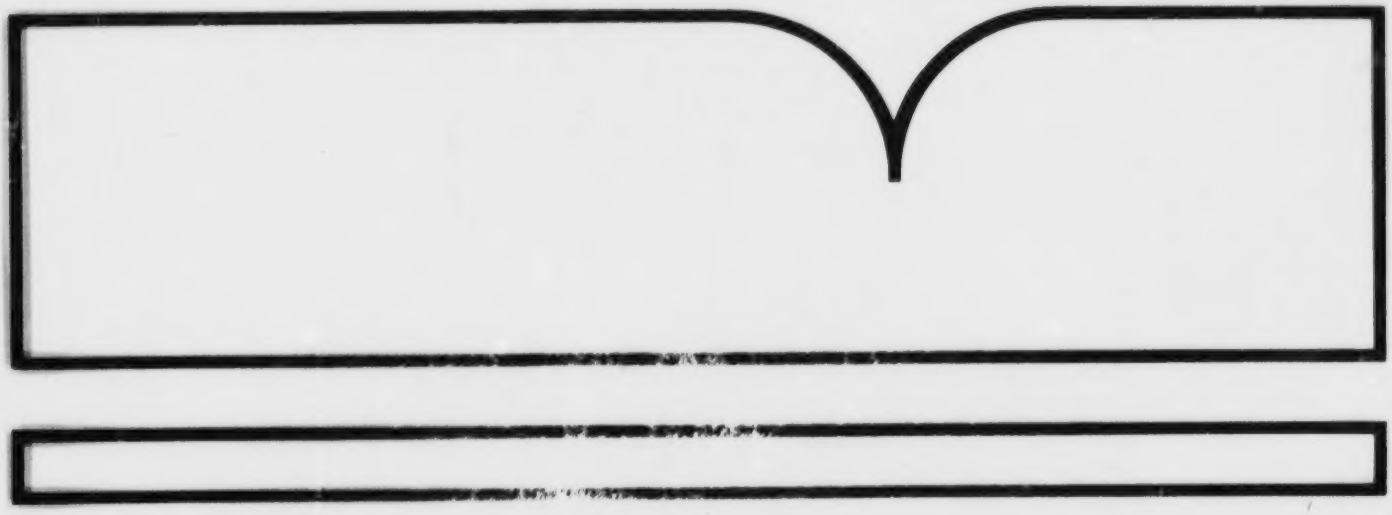

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There is a substantial body of evidence, both direct and indirect, that the mixture that coke oven emissions represent is carcinogenic and toxic. Current U.S. Environmental Protection Agency (EPA) policy stats that there is no zero risk level for carcinogens. To determine what regulatory action should be taken by EPA on atmospheric emissions of coke ovens, three reports have been prepared: (1) a health effects assessment, (2) a population exposure assessment, and (3) a risk assessment document based on the data in the first two assessments. This document is the human population exposure assessment and presents extimates of the number of people in the general population of the United States exposed to atmospheric concentrations of coke ovens emissions. Estimates are provided of population exposures to ambient concentrations of benzo(a)pyrene (BaP) and benzene soluble organics (BSO) material caused by coke oven emissions. Illustrations and tables.

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U.S. ENVIRONMENTAL PROTECTION AGENCY
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Final Report

October 1978

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PREFACE

There is a substantial body of evidence, both direct and indirect, that the mixture that coke oven emissions represent is carcinogenic and toxic. Current U.S. Environmental Protection Agency (EPA) policy states that there is no zero risk level for carcinogens. To determine what regulatory action should be taken by EPA on atmospheric emissions of coke ovens, three reports have been prepared: (1) a health effects assessment, (2) a population exposure assessment, and (3) a risk assessment document based on the data in the first two assessments. This document is the human population exposure assessment and presents estimates of the number of people in the general population of the United States exposed to atmospheric concentrations of coke oven emissions. Estimates are provided of population exposures to ambient concentrations of benzo(a)pyrene (BaP) and benzene soluble organics (BSO) material caused by coke oven emissions.

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CHEMICAL ABBREVIATIONS

A	anthracene
Ant	anthanthrene
BaA	benz(a)anthracene
BaP	benzo(a)pyrene
BbF	benzo(b)fluoranthene
BcA	benzo(c)acridene
BeP	benzo(e)pyrene
BghiP	benzo(g,h,i)perylene
BjF	benzo(j)fluoranthene
BkF	benzo(k)fluoranthene
BSO	benzene soluble organics
Chr	chrysene
Cor	coronene
DBahA	dibenz(a,h)anthracene
Flu	fluoranthene
Per	perylene
Pyr	pyrene
TSP	total suspended particulates

I INTRODUCTION

The primary objective of this study has been to quantify the environmental atmospheric exposure of the general human population to coke-oven emissions of benzo(a)pyrene (BaP) and benzene soluble organics (BSO). To do so, we have located and characterized coke production plants, estimated atmospheric environmental concentrations of pollutants resulting from coke production, and estimated human populations exposed to various levels of these pollutant concentrations.

In this report, we indicate human exposure to coke-oven emissions in terms of the annual average concentrations for residential population subgroups. Note that this study reports exposures that took place before biological sorption occurred and that the degree of sorption is not considered. In addition, because the results of this study are intended to serve as input to another study in which health effects are to be assessed, health effects are not addressed.

The main findings of this report are provided in tables and figures. The text describes the methodologies, assumptions, and data sources used. All estimates given in this report depend in large part on data reliability and availability, both of which varied widely. Some discussion of this variability is provided in Appendices A and B.

II SUMMARY AND CONCLUSIONS

A. Overview

There are 65 by-product coke plants in the United States. (Some authors list 62, omitting separate operations for three of the locations.) These plants consist of an estimated 231 coke-oven batteries, containing 13,324 ovens that have a theoretical maximum annual productive capacity of 74.3 million tons of coke. The industry generally operates at about 80% of the theoretical capacity.

Environmental emissions occur in the coking operation during charging, from leaks in the oven doors and the tops of ovens, from the waste gas stack, during pushing and quenching, and from by-product processing. The various batteries are characterized by different types of control and operational procedures which affect the amount of their emissions. In general, the measurement of environmental emissions from coke ovens has been limited to some atmospheric sampling of BaP for about one-third of the locations. Atmospheric concentrations of TSP have also been measured for many of the locations, and the BSO fraction of the TSP has been measured for a few locations. Atmospheric concentrations of other substances that may be emitted by coke ovens have generally not been recorded. In addition, very little work has been done to characterize detailed emission factors for coke ovens. Because of these limitations, this report's estimates of nonoccupational exposures to coke-oven emissions are based on the two substances for which some atmospheric concentration data are available--BaP and BSO. These two substances might be considered as substitute or surrogate measures of total exposure. However, much more monitoring data will be required before we can conclude that concentrations of these two substances always correlate well with other emitted substances that are important from a health viewpoint.

Atmospheric concentration data recorded during 1964 and 1965 for Birmingham, Alabama, with several coke plants located in the vicinity, showed that the correlation coefficient for BaP with 11 other polynuclear aromatic compounds ranged from 0.65 to more than 0.99. For BSO with 11 other substances, it ranged from 0.58 to 0.88 (U.S. EPA, 1975). In addition, occupational exposure data recorded by NIOSH (1974) show correlation coefficients between BSO and 13 other polynuclear aromatic compounds to range from 0.71 to 0.94. The same study also showed correlation coefficients for BaP with 12 other polynuclear aromatic compounds ranging from 0.57 to 0.95. The substances used in these correlation studies are given in Section III of this report.

It is difficult to use ambient data to assess exposures to coke-oven emissions; most communities have other sources of the same substances,

generally associated with coal and other fossil fuel combustion. Hence, any evaluation of population exposures to coke-oven emissions must separate the background concentration from the coke-oven contribution. Of course, for health risk assessment, the summation of the two is important. Table II-1 reports a BaP emission inventory made by the Environmental Protection Agency (EPA) for 1972. Stationary sources account for 98% of the nationwide estimate. Estimates of BaP emissions from coke ovens for 1972 were approximately 170 metric tons (mt) per year, based on a crude emission factor of 2.5 g of BaP per ton of coal processed. Coke production is estimated to account for approximately 19% of the nationwide BaP emissions. EEA (1978) estimated the 1975 BaP emissions from coke production to be 100 mt. Assuming a 4.2% annual growth in coke demand and improved emission controls, they estimate that the 1985 BaP emission will be 21 mt.

Table II-1

ESTIMATED BaP EMISSIONS IN THE UNITED STATES (1972)

Source Type	Emissions (tonne/yr)
Stationary Sources	
Coal, hand-stoked residential furnaces	300
Coal, intermediate-size units	7
Coal, steam power plants	<1
Oil, residential through steam power type	2
Gas, residential through steam power type	2
Wood, home fireplace	25
Enclosed incineration-apartment through municipal	3
Vehicle disposal	25
Forest and agriculture	11
Other open burning	10
Open burning, coal refuse	310
Petroleum, catalytic cracking	7
Asphalt air blowing	<1
Coke production	170
Mobile Sources	
Gasoline-powered automobiles and trucks	11
Diesel-powered trucks and buses	<1
Tire degradation	11

Source: U.S. EPA (1974)

The exposure estimates given in this report are based on ambient monitoring data recorded in the vicinity of coke-oven locations, generally from 1974 to 1976. Production data used are for 1975. Hence, the exposure estimates apply to the 1975 time period. According to AISI (1978) many new coke-oven emission controls were installed in 1976 and 1977. These were required for implementation of OSHA's new coke-oven emissions standard under the terms of various consent orders. Comparable 1975 and 1976 BaP monitoring data are available from the National Air Surveillance Network (NASN) program for 18 cities having coke plants. These cities had an average BaP concentration of 1.1 ng/m^3 during 1975 and 1.0 ng/m^3 for 1976. These concentrations are not significantly different at the 0.05 confidence level. However, NASN data for a few cities for the first three quarters of 1977 indicate a possible reduction for that year. Because of the latency period associated with cancer development, the 1975 exposure estimates given in this report are considered more relevant for estimating future cancer cases over the next decade than are current exposures.

BaP may also have natural sources, including bituminous coal which also contains benzo(a)anthracene and other polycyclic organic matter. Two of three types of asbestos used industrially were found to contain oils with BaP. Mold may constitute another source (U.S. EPA, 1974).

The NASN routinely monitors suspended particulate levels in urban and nonurban areas. This program is described in more detail in Appendix A. BaP and BSO are monitored for 40 locations that include cities with and without coke ovens and rural areas.* The BaP and BSO concentrations recorded for this program are summarized in Table II-2. The BaP concentrations are generally 0.1 ng/m^3 for rural locations. Most urban locations without coke ovens have average concentrations of less than 1 ng/m^3

Table II-2

SUMMARIZATION OF AMBIENT BaP AND BSO DATA

Pollutant	Statistic	Cities With Coke Ovens	Cities Without Coke Ovens	Rural Areas
BaP (ng/m^3) 1975 data	Average	1.21	0.38	<0.1
	Sample size	21	13	3
	Range	0.3-4.7	0.03-0.9	<0.1
BSO ($\mu g/m^3$) 1971-72 data	Average	4.21	3.75	0.95
	Sample size	25	12	2
	Range	2.1-7.3	1.9-5.6	0.8-1.1

*BSO monitoring was discontinued in 1972.

(the average is 0.38 ng/m^3); however, areas with coke ovens generally have average concentrations in excess of 1 ng/m^3 (the average is 1.21 ng/m^3).

B. At-Risk Population

The at-risk populations to coke-oven emissions are defined as the resident populations exposed to coke-oven atmospheric emissions. Exposure is based on the estimated average annual concentrations occurring at the place of residence of at-risk population subgroups. Average daily human inhalation exposure can be calculated as the product of the average annual concentrations and human daily ventilation rate. The Radiological Health Handbook (1960) gives the daily ventilation rate for a standard man as 15 m^3/day. In a kepone assessment report, EPA (1976b) used a rate of 8.6 m^3/day.

C. Population Estimation

An evaluation of the concentration data shown in Appendix A indicates that coking operations may possibly affect atmospheric concentrations out to a radius of 15 km or more from the operations. For most cases, the affected radius is considerably less than 15 km; however, for conservative analysis, population residing within a 15-km radius from each coke plant is considered as the maximum potential exposure population. For the estimation of populations at-risk to selected concentrations resulting from coke ovens, the resident populations were calculated in a series of five concentric rings about each coke plant. The spacing of the rings was based on the shape of the concentration versus distance functions illustrated in Appendix B. The distances are 0-0.5, 0.5-1.0, 1.0-3.0, 3.0-7.0, and 7.0-15 km.

Geographic coordinates of most of the coke plants were obtained from the U.S. EPA NEDS data system. The remainder were obtained from consulting maps or by telephone conversations. The population residing in each concentric ring about each coke plant was obtained from the Urban Decision Systems, Inc., Area Scan Report, a computer data system that contains the 1970 census data in the smallest geographic area available (city blocks and census enumeration districts). The total population residing in each of these rings for all the coke plants is as follows:

Distance from Coke Plant (km)	Resident Population
0-0.5	32,700
0.5-1	116,000
1-3	1,644,000
3-7	7,226,000
7-15	22,200,000

The total population residing within 15 km of the coke plants is approximately 31,220,000 people. In the exposure calculations it was found that only about 17,100,000 of these people were affected* by coke-oven emissions.

D. Population Exposures to BaP Emitted by Coke Ovens

The annual average BaP atmospheric concentrations were estimated for each of the five concentric rings around each of the coke plants. Recorded ambient data were used for those locations having a sufficient number of samples and monitoring sites; otherwise, the extrapolative modeling techniques described in Section IV were used. These modeling techniques assume that the annual average atmospheric BaP concentrations near coke ovens can be expressed as a mathematical function of the amount of coal processed, emission controls, distance from the coke ovens, and background concentrations from other sources. The constants of the models were statistically estimated, based on ambient data recorded for some of the locations. The models were then extrapolated to other locations for which no ambient data have been recorded. Because of the difficulty in estimating background concentrations for coke-oven locations, two different types of models are used to give alternative exposure estimates. One model type assumes variable BaP background concentrations, whereas the other assumes constant background concentrations. For locations with several coke plants, a procedure was devised to assess the combined atmospheric concentrations by summing the contribution for individual plants for areas in overlapping geographic rings.

Atmospheric concentrations resulting from coke-oven emissions were calculated, as were total concentrations including background plus coke-oven emissions. Because of the uncertainty involved in estimating exposures, several alternative estimates are given under varied assumptions. Of the three alternatives given in Table II-3, one assumes that coke plants, for which no monitoring data are available, can be assigned to either well and poorly controlled groups; two other estimates use available monitoring data and assume all other plants are either well or poorly controlled.

Two additional exposure estimates are given in Table II-4. Each assumes a uniform background BaP concentration for all locations (i.e., 0.4 and 1.0 ng/m^3). Monitoring data are used when available for the exposure estimates. For other plants well and poorly controlled mathematical functions are used.

All alternative exposure estimates give annual average population exposure concentrations ranging from 0.2 (the lower value used) to 100 ng/m^3. Depending on the assumptions used, the total number of exposed

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*Coke-oven emissions resulted in an increase in the average annual atmospheric BaP concentrations of 0.2 ng/m^3 or more.

Table II-3

ESTIMATED NUMBER OF PEOPLE EXPOSED TO BaP FROM COKE-OVEN EMISSIONS, ASSUMING VARIABLE LOCATION BACKGROUND CONCENTRATIONS*

Subgroup Concentration Range† (ng/m^3)	Assumption		
	Stratified Grouping	All Well Controlled**	All Poorly Controlled**
95-100	1,800	1,800	1,800
65-95	-	-	-
60-65	-	-	-
55-60	-	-	-
50-55	870	-	-
45-50	50	870	940
40-45	1,500	1,530	5,490
35-40	1,700	1,560	1,690
30-35	2,400	-	2,370
25-30	1,600	1,020	4,430
20-25	9,000	8,710	16,270
15-20	63,700	40,670	60,510
10-15	137,300	105,910	139,150
8-10	442,700	442,760	668,520
6-8	136,300	42,940	144,110
5-6	196,300	182,240	244,640
4-5	187,100	127,100	187,860
3-4	798,300	248,890	1,526,670
2-3	1,245,200	865,670	1,374,360
1-2	5,026,700	3,311,630	7,721,760
0.5-1	4,679,600	4,535,290	6,656,530
0.2-0.5	4,183,500	3,763,130	5,396,800
Total	17,106,620	13,681,720	24,153,900

*Excludes background concentrations.

†Based on annual averages.

**That is, all coke plants for which no monitoring data exist.

- No exposures are estimated for this concentration range.

Table II-4

ESTIMATED NUMBER OF PEOPLE EXPOSED TO BaP FROM COKE-OVEN EMISSIONS, ASSUMING UNIFORM BACKGROUND CONCENTRATIONS*

Subgroup Concentration Range** (ng/m^3)	Assumed Background	
	0.4 ng/m^3	1.0 ng/m^3
95-100	1,800	1,800
65-95	-	-
60-65	50	50
55-60	-	-
50-55	100	100
45-50	900	900
40-45	3,900	3,900
35-40	2,110	1,880
30-35	-	-
25-30	5,730	1,510
20-25	31,610	31,770
15-20	68,170	72,240
10-15	134,730	109,000
8-10	1,097,020	688,800
6-8	181,550	161,380
5-6	120,690	55,170
4-5	1,264,960	154,420
3-4	1,076,410	774,800
2-3	2,225,320	1,028,420
1-2	4,350,930	2,746,150
0.5-1	5,487,600	2,180,560
0.2-0.5	3,064,120	2,720,240
Total	19,117,700	10,733,090

*Excludes background concentrations.

**Based on annual averages.

- No exposures are estimated for this concentration range.

people so estimated ranges from 10 to 24 million. The "better estimates" give 17 to 19 million people exposed. In no case were exposures estimated beyond 15 km from the plants. Had this constraint been relaxed, more people exposed would have been assigned to the lower concentrations, especially in the case that assumes a uniform background concentration of 0.4 ng/m^3.

The total background plus coke-oven exposures are given in Table II-5. Note that, because the procedure used first estimated total exposure from which background concentrations are subtracted, total exposures are the same for the two uniform background assumption cases. Detailed exposure estimates for the variable background are given in Appendix C.

E. Population Exposures to BSO Emitted by Coke Ovens

Sufficient data have not been collected near coke plants nor have emission factors been developed for adequately assessing the atmospheric BSO concentrations resulting from the plants' emissions. The approach taken here is to estimate the BSO concentrations, based on the estimated BaP concentrations. A number of problems are associated with this approach, however, and the results can, at best, be described as "ballpark estimates." Further work on assessing plant emission factors or measuring environmental concentrations should help to improve the quality of future estimates.

The approach taken here, which is described in Section IV, assumes that BaP constitutes 1% of the total BSO emitted by coke ovens. Three of the alternative BaP exposure estimate techniques are used to provide three alternative BSO estimates. The estimated exposures to BSO from coke ovens only are given in Table II-6. Annual average concentrations are shown to range as high as 10 $\mu g/m^3$. Because of the lack of sufficient data, estimates are not given for BSO exposures due to coke ovens plus background. Table II-2 shows that the 1971-72 concentrations for cities without coke ovens averaged 3.75 $\mu g/m^3$. Hence, adding this value to the exposure concentrations given in Table II-6 would give a rough estimate of total BSO exposure. This, however, may not be proper because the constitution of the background BSO may likely differ from that of the BSO emitted by coke ovens.

F. Considerations in the Use of the Annual Average as a Measure of Exposure to Coke-Oven Emissions

Exposure estimates in this report are given in terms of the daily exposure averaged over a year. Statistically, this measure represents the expected daily exposure; multiplied by 365, it gives the total expected annual exposure. However, the statistical distribution of concentrations for a specific location is not symmetrical; rather, it takes the form of many relatively small observations and a few relatively

Table II-5

ESTIMATED NUMBER OF PEOPLE EXPOSED TO BaP FROM COKE-OVEN EMISSIONS, INCLUDING BACKGROUND

Subgroup Concentration Range* (ng/m^3)	Background Assumption	
	Variable†	Uniform**
95-100	1,800	1,800
65-95	-	-
60-65	-	50
55-60	-	-
50-55	870	970
45-50	50	2,410
40-45	1,500	2,090
35-40	1,700	2,560
30-35	3,400	1,020
25-30	4,800	4,710
20-25	5,000	27,540
15-20	63,700	72,240
10-15	547,400	563,240
8-10	75,100	694,600
6-8	275,700	130,250
5-6	116,700	139,390
4-5	248,200	1,428,340
3-4	1,723,100	1,105,700
2-3	4,266,600	2,706,250
1-2	907,900	3,726,030
0.5-1	8,863,100	8,508,510
<0.5		
Total	17,106,620	19,117,700

*Based on annual averages.

†Based on the stratified grouping assumptions.

**Based on the 0.4-ng/m^3 background assumption.

- No exposures are estimated for this concentration range.

Table II-6

ESTIMATED NUMBER OF PEOPLE EXPOSED TO BSO
FROM COKE-OVEN EMISSIONS*

Subgroup Concentration Range** ($\mu g/m^3$)	Estimation Procedure		
	Variable BaP Background	BaP Background of 0.4 ng/m^3	BaP Background of 1 ng/m^3
9.5-10	1,800	1,800	1,800
6.5-9.5	-	-	-
6.0-6.5	-	50	50
5.5-6.0	-	-	-
5.0-5.5	870	100	100
4.5-5.0	50	900	900
4.0-4.5	1,500	3,900	3,900
3.5-4.0	1,700	2,110	1,880
3.0-3.5	2,400	-	-
2.5-3.0	1,600	5,730	1,510
2.0-2.5	9,000	31,610	31,770
1.5-2.0	63,700	68,170	72,240
1.0-1.5	137,300	134,730	109,000
0.8-1.0	442,700	1,097,020	688,800
0.6-0.8	136,300	181,550	161,380
0.5-0.6	196,300	120,690	55,170
0.4-0.5	187,100	1,264,960	154,420
0.3-0.4	789,300	1,076,410	774,800
0.2-0.3	1,245,200	2,225,320	1,028,420
0.1-0.2	5,026,700	4,350,930	2,746,150
0.05-0.1	4,679,600	5,487,600	2,180,560
0.02-0.05	4,183,500	3,064,120	2,720,240
Total	17,106,620	19,117,700	10,733,090

*Excludes background concentrations.

**Based on annual averages.

- No exposures are estimated for this concentration range.

larger observations. Examples of these distributions are given in Appendix B. The averages for these types of distributions are much larger than the median and, generally, only 20% to 40% of the observations might be expected to exceed the mean in value. The geometric average, rather than the arithmetic average, is a better measure to characterize the central location of these distributions. The overall arithmetic average was found to be 1.8 times as large as the geometric average (Appendix B).

Calculations of averages and standard deviations are given in Appendix B for BaP concentration data recorded over a number of different days at a specific location. For most of these locations, the average was found to equal the standard deviation. Thus, concentrations for an individual worst case day could easily be three times the annual average.

G. Accuracy of Estimated Exposures

1. BaP Estimates

The overall accuracy of the BaP exposure estimates is difficult to assess because many relevant factors are either unknown or violate statistical randomization principles. In addition, certain sources of error cannot be adequately quantified with available information. Examples of the major sources of error are described in the following paragraphs.

a. Errors in Estimating Background Concentrations. Monitoring data contain both background and coke-oven emission contributions to BaP concentrations. Hence, background concentrations must be subtracted from monitoring data to estimate coke-oven contributions. However, accurately estimating background concentrations for most locations is difficult because of insufficient monitoring data or lack of other source emission analyses. The rough estimates made of background concentrations may, in some cases, be quite inaccurate. Because this is an important source of error in estimating the population exposures to the lower concentrations, the effect of the assumed background concentrations on population exposures has been parametrically analyzed by using three alternative background concentration cases. These are shown in Tables II-3 and II-4. The background assumptions can account for errors in total exposures of about ±30%.

b. Errors from Using Samples from a Limited Number of Days to Represent Annual Averages. Data given in Appendix B show that the day-to-day variations in BaP concentrations for a monitoring station follow a skewed statistical distribution of a log-normal type. The average geometric standard deviation is approximately 2 and the coefficient of variation is 100, indicating that the one-standard deviation confidence limits for variations in 24 hour concentrations are 100% of the mean. Appendix B also gives factors to adjust the standard deviation for

individual daily means to the standard deviation for annual mean. These factors are based on the number of days of available data. Use of these factors shows that the one-standard deviation confidence limits for the annual mean based on the sample mean would vary from 25% to 100%. That is, the one-standard deviation confidence limits would be 0.8 to 1.25 times the estimated mean for the best case and 0.5 to 2 times the estimated mean for the worst case.

c. Errors in Applying Observed Data from Coke Plants to Coke Plants with No Observed Data. The potential errors in estimated exposure concentrations were addressed by using the variable background model to predict average annual concentrations for 1- and 3-km distances for a number of coke plants for which environmental monitoring data are available. The discrepancies between the observed and predicted concentrations then provide an estimate of the accuracy of the procedure. The one-standard deviation on these discrepancies was about 100%. This indicates that the one-standard deviation confidence limits on a predicted value are one-half to two times that value. An error of at least this magnitude would be expected when the model is applied to locations for which no monitoring data have been recorded. In addition, alternative exposure estimates are arrived at by assuming that all plants for which no monitoring data are available are either poorly or well controlled.

d. Errors from Assuming Circular Concentration Contours. The actual residential population distribution was used for the exposure estimates given in this report; however, it was assumed that the annual average BaP isoconcentration contours about each coke plant are circular. This, in effect, assumes that over a year the wind blows equally from all directions; more specifically, the wind blows toward the direction of the major populated areas in a manner similar to that if it were blowing equally toward all directions. This obviously is not true for all coke plant locations. Generally, the annual average isoconcentration contours will be elongated in the directions in which the wind blows more frequently and shortened in the directions in which the wind blows less frequently. Depending on the actual residential locations for specific coke plants, this assumption may result in over- or under-estimates of exposed populations. However, this report presents total estimated population exposures for all coke plants. Because more than 60 coke plants are located throughout the country, the over- and under-estimates for specific locations should tend to compensate for one another, resulting in national exposure estimates that are approximately correct.

The circular isoconcentration contour assumption was analyzed to determine if it would result in gross over- or under-estimates of total exposures. The analysis compared the ratio of the actual and assumed wind directional-frequency data (which are summarized on a figure called a wind rose) with the actual population distribution. The wind roses used in this analysis show the percent of time, over a year, that the wind blows from each of 16 equally spaced compass directions and the

percent of time that calm conditions exist. Each of the 16 compass directions represent a 22.5° sector. The compass direction having the highest percentage of winds is sometimes called the direction of prevailing wind. However, note that to fulfill this definition the wind need only blow from the prevailing wind direction a small fraction of the time more than from other directions.

The uniform wind direction assumption implies that the wind blows 6.25% of the time from each of the sectors represented by the 16 compass direction wind rose (assuming no calm periods). The ratio of the actual percent of time the wind blows to 6.25% for a compass direction indicates the degree in which the isoconcentration contours should be elongated or shortened toward the diametrically opposing 22.5° sector. This ratio, therefore, indicates the degree of over- or under-exposure estimation for that sector resulting from the circular isoconcentration assumption. Mathematically, this may be expressed as:

$$g_i = \left(a_i / U_i\right) \cdot \left(100 \Big/ \sum_{i=1}^{16} a_i\right)$$

where

g_i = the ratio of actual to assumed wind frequencies for a sector

a_i = the actual wind frequency (%) for a sector taken from a wind rose

U_i = 6.25%, the uniform wind frequency.

As examples, if g = 0.5, population exposure concentrations for that sector are overestimated by 50%; if g = 2.0, then population exposure concentrations for that sector are underestimated by 50%. The total fractional error for the estimated exposures for one location can be approximated by

$$E = \sum_{i=1}^{16} P_i g_i \Big/ \sum_{i=1}^{16} P_i$$

where

E = the total fractional error

g_i = the ratio as previously defined

P_i = the residential population in each 22.5° sector.

The SRI data base containing the U.S. population on 1-km grids was printed for the area about each coke plant. These areas were each divided in sixteen 22.5° sectors radiating from each coke plant. It was then determined whether a relatively significant number of residents

would be exposed in each sector and, based on this determination, corresponding values of 1 or 0 were assigned to P_i. The total fractional error (E) was then calculated for each coke plant; these are given in Table II-7. Individual coke plant values were found to vary from 0.55 to 1.58 with an average value of 0.96. The average weighted by population residing within 15 km of the coke plants was 0.97. Hence, when calm conditions are excluded, the circular isoconcentration contour assumption may result in overexposure estimate of about 3% to 4%. The average calm conditions occur at each plant 4% of the time. During calm conditions, adjacent residential populations will be exposed to very high concentrations, which were not considered in this report. Thus, the total overestimate should be less than 4%.

e. Total Error. Because of the many uncertainties, an accurate assessment of the total error associated with the BaP exposure estimates cannot be made. The estimates are not expected to be highly accurate for any location. The overall exposure estimates, which are a summation of the exposures about individual plants, are expected to be more accurate because they were formulated by using averages of parameters that represent a range of meteorological, geographical, and emission control conditions.

2. BSO Estimates

The BSO exposure estimates are based on the BaP estimates. Thus, they contain not only the errors associated with estimating BaP exposures but also an additional error source caused by relating BSO to BaP. Occupational data are evaluated in Section IV-D of this report to determine the magnitude of this error source. To do this, the BaP concentrations were used to estimate corresponding BSO concentrations; the estimated concentrations were then compared with recorded BSO concentrations. The one-standard deviation for the differences between the predicted and observed concentrations was found to be 53% for individual values and 10% for the mean.

H. Other Potential Human Exposure Routes

There are potential human exposure routes for coke-oven emissions other than inhalation. These include ingestion of contaminated food and water and dermal contact. In addition, family members of occupational workers might be exposed through particulates brought home on clothing and other equipment such as lunch pails and automobiles. An assessment of potential human exposures via these routes was excluded from the scope of this study because they either appear to be much less significant than the inhalation route or because of the lack of available data.

Table II-7

RELATIVE ERROR IN EXPOSURE ESTIMATES ASSUMING CIRCULAR ISOCONCENTRATION CONTOURS

Site No.*	No. of Sectors†	Relative Error**	Site No.*	No. of Sectors†	Relative Error**	Site No.*	No. of Sectors†	Relative Error**	Site No.*	No. of Sectors†	Relative Error**
1	8	0.96	17	7	0.73	32	5	0.59	47	11	0.94
3	8	0.81	18	7	0.73	33	4	0.75	49	10	1.19
4	10	0.95	19	6	0.78	35	8	0.91	50	13	0.99
5	12	1.01	20	7	0.73	36	6	0.51	51	11	1.18
6	9	0.96	21	9	0.84	37	9	1.34	52	10	0.67
7	11	0.77	22	9	0.77	38	13	1.04	53	11	1.18
8	7	0.55	23	12	1.09	39	7	1.36	54	11	0.82
10	11	0.92	24	9	1.12	40	12	1.04	55	8	0.59
11	11	0.90	25	11	1.13	41	15	0.94	56	11	1.17
12	11	0.89	27	4	1.58	42	13	1.00	57	9	0.69
13	11	0.89	28	7	1.04	43	10	0.95	58	4	1.19
14	6	0.87	29	6	1.48	44	16	1.09	60	9	1.11
15	13	0.96	30	8	1.41	45	7	0.53	64	10	0.83
16	13	1.05	31	10	1.28	46	11	0.94			

*Corresponds to site numbers given in Table III-3. Some sites are excluded because of insignificant exposures or insufficient data available.

†Number of the sixteen 22.5° sectors for which significant population exposures are estimated.

**Values less than 1 indicate overestimates and values more than 1 indicate underestimates.

Foods can become contaminated because of atmospheric fallout of particulates or by way of contaminated water released by the coke plant. The contamination may be on the surface of plants from fallout or included by root-uptake. Animals can become contaminated by drinking contaminated water, eating contaminated foods, or breathing contaminated air. Contamination may also result from other man-made or natural sources. Processed foods may contain additional contaminations from the combustion of fuels used in smoking, roasting, or broiling. Foods in general have been found to contain concentrations of polynuclear aromatic hydrocarbons such as benzo(a)anthracene, chrysene, and benzo(a)pyrene (Radding et al., 1976). Table II-8 lists concentration levels of BaP in some foods. As expected, the BaP concentration of certain prepared foods is higher than for other foods. At present, insufficient information is available to access the potential contamination of foods by coke-oven emissions.

Table II-8

BENZO(A)PYRENE CONCENTRATIONS IN FOODS

Food	Concentration (μg/kg)	Reference
Cereals	0.3-0.8	A
Potato peelings	0.36	A
Potato tubers	0.09	A
Barley, wheat, rye	0.2-4.1	B
Cabbage	24.5	B
Spinach	7.4	C
Lettuce	2.8-12.8	B
Tomatoes	0.22	B
Fruits	2.0-8.0	C
Refined fats and oils	0.9-15	C
Fresh fish	<0.1	D
Broiled meat and fish	0.2-0.6	C
Smoked fish	1.0-78.0	E
Smoked meat/sausage	0.02-107.0	C
Roasted coffee	0.3-0.5	B
Roasted coffee	0.1-4.0*	C
Teas	3.7-3.9*	B
Whiskey	0.04*	B

*μg/ℓ.

A--Shabad (1972)
B--Grummer (1968)
C--IRAC (1973)
D--Gorelova (1971)
E--Andelman (1970)

Polynuclear aromatic hydrocarbons find their way into waterways already absorbed onto aerosols or bacteria. Although their solubility in pure water is essentially zero, they may exist in water in association with organic matter or colloids (Radding et al., 1975). The IRAC (1973) report lists BaP concentrations in drinking water of 0.0001 to 0.023 µg/ℓ.

III SOURCES OF COKE OVEN EMISSIONS

A. The Coking Process*

Coke is a porous cellular residue from the destructive distillation or carbonization of coal. It is used as a fuel and reducing agent in blast furnace operations, and in foundries as a cupola fuel. Of the approximately 60 million tons of coke produced annually in the United States, 92% is used in blast furnaces, 5% in foundry operations, and 3% in other types of industrial plants. Of the total coke production, approximately 90% is produced by steel industry plants, 8% by foundry plants, and 1% by beehive ovens.

Two basic processes are used in the production of coke: One recovers vapors and other by-products from the coking process (by-product ovens), and one does not (beehive ovens). The beehive oven, an older design, that has been steadily replaced by the newer by-product design is excluded from this analysis.

A by-product coke battery consists of 10 to 100 ovens made up of chambers for heating, coking, and regeneration. Heating and coking flues alternate with each other so that there is a heating flue on either side of a coking flue; the regenerative flues are located underneath.

The coking cycle begins with the introduction of coal into the coke oven. This operation, called "charging," is carried out with a mechanical "larry car" on rails on the top of the battery. The larry car receives a load of coal from the coal bunker at the end of the battery. The car moves down the battery to the oven to be charged. The lids on the oven charging holes are removed, the larry car is positioned over the holes, and the hoppers are emptied. During the charge, the oven is aspirated by steam jets in the standpipes connecting the by-product gas collector main with the oven. This operation, called "charging the main" is designed to limit the escape of gas from the oven during the charging process. After charging is completed, the lids are replaced and the aspiration system is shut off.

The "coking time," the time required to produce coke from coal, is governed by numerous factors, including the condition and design of the oven heating system, width of the coking chamber, coal moisture, and the nature of the coals being coked. The coking time for blast furnace coke varies from 16 to 20 hours. Coking times for foundry coke are longer than

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*The material contained in this section is summarized from the Federal Register (October 22, 1976).

for blast furnace coke because coke of different physical characteristics is required for foundry operations.

When the coal is coked, the doors on each side of the oven are removed and the coke is pushed out. A large mechanically operated ram attached to a pusher machine moves the coke out the opposite side of the oven called the "coke side," through the "coke-guide" attached to the door machine and into a railroad car called the "hot car" or "quench car." The quench car moves down the battery to a "quench tower" where the hot coke is cooled with water. The quenched coke is then dumped onto the coke wharf, from which it is conveyed to the screening station for sizing, then to the blast furnace, or removed for other purposes. When the doors on the oven are replaced, the oven is ready to be charged again.

B. Environmental Emissions During Coking

Environmental emissions can occur during charging; during coking from leaks in the doors and on the top of the oven; from the waste gas stack; and during pushing and quenching, and from by-product processing. Coke-oven emissions are described as a complex mixture of particulates, vapors, and gases (Federal Register, October 22, 1976).

Because of the effort and complexity that would be required in characterizing all of the constituents of coke-oven emissions, various surrogate measures have been used in the past. These usually are of three types: TSP,* BSO, and BaP. TSP is generally considered not to be a specific enough measure for assessing total occupational health effects (Federal Register, October 22, 1976). The concept of a surrogate measure would be valid if it could be shown that that measure correlates well with the presence of other emitted substances known to have adverse health effects. Atmospheric concentration data recorded during 1964 and 1965 for Birmingham, which has several coke plants in the surrounding area, showed that the correlation coefficient for BaP with 11 other substances ranged from 0.65 to more than 0.99. For BSO with 11 other substances the coefficient ranged from 0.58 to 0.88 (U.S. EPA, 1975), indicating a fairly good association. These are given in Table III-1. In an occupational exposure study, the atmospheric concentrations of 13 polynuclear aromatics (PNAs) and the total benzene soluble organics were recorded. A correlation study was made of these data using logarithmic transformations because the data followed a log-normal distribution (NIOSH, 1974). The correlation of the PNAs with BaP and BSO are given in Table III-2. Except for one case, all the correlation coefficients exceeded 0.7, thus indicating a fairly good correlation. The correlation of BSO with the 13 PNAs was generally better than the similar correlations for BaP.

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*TSP--total suspended particulates.

Table III-1

CORRELATIONS AMONG PAH COMPOUNDS
IN THE AIR OVER GREATER BIRMINGHAM,
ALABAMA, 1964 AND 1965

	Compound		
Compound	BaP	BSO	TSP
Flu	0.916	0.582	0.668
Pyr	0.935	0.684	0.730
BaA	0.988	0.597	0.742
Chr	0.980	0.746	0.842
BeP	0.998	0.677	0.823
BaP	1.000	0.651	0.789
Per	0.985	0.689	0.830
BghiP	0.966	0.804	0.839
A	0.971	0.672	0.716
Cor	0.815	0.867	0.856
TSP	0.789	0.880	1.000
BSO	0.651	1.000	0.888

Source: U.S. EPA (1975)

Table III-2

CORRELATION COEFFICIENTS AMONG LOG
CONCENTRATIONS OF 13 PNA AND BSO
SAMPLES TAKEN WITHIN FIVE COKE PLANTS

Compound	BaP	BSO
Flu	0.797	0.914
Pyr	0.740	0.862
BcA	0.569	0.713
Chr	0.857	0.936
BaA	0.824	0.909
BbF	0.776	0.884
BjF	0.768	0.894
BkF	0.813	0.915
BeP	0.950	0.922
BaP	1.000	0.914
DBahA	0.694	0.725
BghiP	0.855	0.875
Ant	0.892	0.905
BSO	0.914	1.000

Source: NIOSH (1974)

The occupational and the Birmingham correlation studies provide some justification for using a surrogate measure rather than trying to identify and control each of the PNA compounds emitted by coke ovens.

C. Coke Processing Plants

In 1975, 57.2 million tons of coke were produced in the United States. By-product ovens produced 98.7% of the total production, with beehive ovens accounting for the remaining 1.3%. Approximately 90% of the coke is used in blast furnace plants, whereas 2% is exported. The remainder is primarily used in foundries. The yield of coke from coal, which averaged 68.4% in 1975, has remained fairly constant during the past decade (Sheridan, 1976).

In the United States, 65 plants produce coke. (Some authors list only 62 by combining three pairs of closely collocated plants, where each pair of plants are owned by the same corporation.) The 65 plants are listed in Table III-3 which also lists the coal capacity and the 1974 coal consumption on a plant-by-plant basis. The plants consist of an estimated 231 coke-oven batteries containing 13,324 ovens that have a theoretical maximum annual productive capacity of 74.3 million tons of coke. Because of depressed economic activity in 1975, the industry operated at only 76% of this capacity. Coke production on a state-by-state basis is given in Table III-4.

The Keystone Coal Industries Manual (1975) lists six beehive-coke plants. These operate in two states (Pennsylvania and Virginia). Although excluded from this analysis, they are listed in Table III-5.

Table III-3

BY-PRODUCT COKE PLANT LOCATIONS AND CAPACITIES

State, City	Plant Name	Company	Annual Coal Capacity (tons)	1974 Coal Consumption (tons)
Alabama				
1. Tarrant	Tarrant Plant	Alabama By-Products Co.	1,200,000	
2. Holt	Holt Plant	Empire Coke Co.	150,000	
3. Woodward	Woodward Plant	Koppers Company, Inc.	800,000	
4. Gadsen	Gadsden Plant	Republic Steel Corp.	820,000	
5. Thomas	Thomas Plant	Republic Steel Corp.	185,000	
6. Birmingham	Birmingham Plant	U.S. Pipe and Foundry Co.	1,175,000	
7. Fairfield	Fairfield Plant	U.S. Steel Corp.	2,500,000	
California				
8. Fontana	Fontana Plant	Kaiser Steel Corp.	2,336,000	1,760,000
Colorado				
9. Pueblo	Pueblo Plant	CF&I Steel Corp.	1,332,000	
Illinois				
10. Granite City	Granite City Steel Div.	National Steel Corp.	1,132,000	900,000
11. Chicago	Chicago Plant	Interlake, Inc.	949,000	
12. Chicago	Wisconsin Steel Works	International Harvester Co., Wisconsin Steel Div.	991,000	643,000
13. South Chicago	South Chicago Plant	Republic Steel Corp.	590,000	
Indiana				
14. Chesterton	Burns Harbor Plant	Bethlehem Steel Corp.	2,630,000	2,525,000
15. Indianapolis	Prospect Street Plant	Citizens Gas & Coke Utility	675,000	584,838
16. Terre Haute	Terre Haute Plant	Indiana Gas and Chemical Corp.	204,000	193,000
17. East Chicago	Plant No. 2	Inland Steel Co.	3,102,000	3,096,000
18. East Chicago	Plant No. 3	Inland Steel Co.	1,642,000	1,258,000
19. Gary	Gary Plant	U.S. Steel Corp.	3,700,000	
20. Indiana Harbor	Indiana Harbor Plant	Yougstown Sheet and Tube Co.	2,100,000	1,750,000
Kentucky				
21. Ashland	Semet	Solvay Div., Allied Chemical Corp.	1,600,000	
Maryland				
22. Sparrows Point	Sparrows Point Plant	Bethlehem Steel Corp.	4,820,000	4,100,000
Michigan				
23. Detroit	Semet	Solvay Div., Allied Chemical Corp.	900,000	
24. Dearborn	Steel Plant	Ford Motor Co.	1,800,000	
25. Zug Island (Detroit)	Zug Island Plant	Great Lakes Steel Div., National Steel Corp.	2,850,000	
Minnesota				
26. St. Paul	St. Paul Plant	Koppers Company, Inc.	250,000	
27. Duluth	Duluth Plant	U.S. Steel Corp.	850,000	
Missouri				
28. St. Louis	St. Louis Plant	Great Lakes Carbon Corp., Missouri Coke & Chem. Div.	450,000	
New York				
29. Buffalo	Harriet Plant	Semet-Solvay Div., Allied Chemical Corp.	400,000	
30. Lackawana	Lackawana Plant	Bethlehem Steel Corp.	4,250,000	3,385,000
31. Buffalo	Donner-Hanna Plant	Donner-Hanna Coke Corp.	1,387,000	

Table III-3 (Concluded)

State, City	Plant Name	Company	Annual Coal Capacity (tons)	1974 Coal Consumption (tons)
Ohio				
32. Ironton	Ironton Plant	Semet-Solvay Div., Allied Chemical Corp.	1,230,000	
33. New Miami	Hamilton Plant	Armco Steel Corp.	934,000	
34. Middletown	Middletown Plant	Armco Steel Corp.	748,000	
35. Painesville	Painesville Plant	Diamond Shamrock Corp.	215,000	210,000
36. Portsmouth	Empire	Detroit Steel Div. of Cyclops Corp.	600,000	
37. Toledo	Toledo Plant	Interlake Inc.	438,000	
38. Cleveland	Cleveland Plant	Republic Steel Corp.	2,220,000	
39. Massilon	Massilon Plant	Republic Steel Corp.	250,000	
40. Warren	Warren Plant	Republic Steel Corp.	650,000	
41. Youngstown	Youngstown Plant	Republic Steel Corp.	1,500,000	
42. Lorain	Lorain Cuyahoga Works	U.S. Steel Corp.	2,700,000	
43. Campbell	Campbell Plant	Youngstown Sheet and Tube Co.	2,300,000	1,895,116
Pennsylvania				
44. Swedeland	Alan Wood Plant	Alan Wood Steel Co.	803,000	
45. Bethlehem	Bethlehem Plant	Bethlehem Steel Corp.	2,210,000	2,105,000
46. Johnstown	Rosedale Div.	Bethlehem Steel Corp.	550,000	545,000
47. Johnstown	Franklin Div.	Bethlehem Steel Corp.	1,680,000	1,645,000
48. Midland	Alloy & Stainless Steel Div.	Crucible Inc., Div. Colt Industries	657,000	630,000
49. Aliquippa	Aliquippa Plant	Jones and Laughlin Steel Corp.	2,250,633	
50. Pittsburgh	Pittsburgh Plant	Jones and Laughlin Steel Corp.	2,587,404	
51. Erie	Erie Plant	Koppers Company, Inc.	290,000	
52. Philadelphia	Philadelphia Plant	Philadelphia Coke Division	715,400	385,000
53. Pittsburgh	Neville Island Plant	Shenango Inc.	1,022,000	823,900
54. Clairton	Clairton Plant	U.S. Steel Corp.	9,670,000*	
55. Fairless Hills	Fairless Hills Plant	U.S. Steel Corp.	1,800,000	
56. Monessen	Wheeling	Pittsburgh Steel Corp.	750,000	
Tennessee				
57. Chattanooga	Chattanooga Plant	Chattanooga Coke and Chemicals Co.	204,400	
Texas				
58. Houston	Houston Plant	Armco Steel Corp.	584,000	
59. Lone Star	E. B. Germany Plant	Lone Star Steel Co.	498,000	492,000
Utah				
60. Provo	Geneva Works	U.S. Steel Corp.	2,000,000	
West Virginia				
61. Weirton	Weirton Mainland Plant	Weirton Steel Div., National Steel Corp.	2,500,000	
62. Weirton	Weirton's Brown's Island Plant	Weirton Steel Div., National Steel Corp.	1,825,000	
63. Fairmont	Fairmont Plant	Sharon Steel Corp.	300,000	284,000
64. Follonsbee	East Steubenville Plant	Wheeling-Pittsburgh Steel Corp.	2,500,000	
Wisconsin				
65. Milwaukee	Milwaukee Solvay Coke Co.	A Division of Picklands Mather and Co.	347,000	

*Based on a 1973 emission inventory.

Sources: Keystone Coal Industries Manual (1975)
Varga (1974)

Table III-4

ESTIMATED SIZE AND PRODUCTIVE CAPACITY OF BY-PRODUCT COKE PLANTS IN THE UNITED STATES ON DECEMBER 31, 1975

State	Number of Plants	Number of Batteries	Number of Ovens	Maximum Annual Theoretical Productive Capacity (tons)	Coke Production in 1974 (tons)
Alabama	7	28	1,401	6,961,000	5,122,000
California	1	7	315	1,547,000	*
Colorado	1	4	206	1,261,000	*
Illinois	4	9	424	2,523,000	1,912,000
Indiana	6 (7)	31	2,108	11,925,000	9,073,000
Kentucky	1	2	146	1,050,000	*
Maryland	1	12	758	3,857,000	*
Michigan	3	10	561	3,774,000	3,259,000
Minnesota	2	5	200	784,000	*
Missouri	1	3	93	257,000	*
New York	3	10	648	4,053,000	*
Ohio	12	35	1,795	9,960,000	8,842,000
Pennsylvania	12 (13)	51	3,391	18,836,000	16,318,000
Tennessee	1	2	44	216,000	*
Texas	2	3	140	839,000	*
Utah	1	4	252	1,300,000	*
West Virginia	3 (4)	13	742	4,878,000	3,555,000
Wisconsin	1	2	100	245,000	*
Undistributed	--	--	--	--	12,656,000
Total	62 (65)	231	13,324	74,266,000	60,737,000

*Included in Undistributed.

Source: Sheridan (1976)

Table III-5

DIRECTORY OF U.S. BEEHIVE-COKE PLANTS

Name or Location of Plant	County	Company
Pennsylvania		
1. Mahoning	Armstrong	Caipentown Coal & Coke Co.
2. Daugherty	Fayette	Bortz Coal Company
3. Laughead	Fayette	Ruane Coal & Coke Company
Virginia		
5. Vansant	Buchanan	Jewell Smokeless Coal Corp.
6. Esserville	Wise	Christie Coal & Coke

Source: Keystone Coal Industries Manual (1975)

IV A METHOD OF ASSESSING BaP AND BSO CONCENTRATIONS IN THE VICINITY OF COKE OVENS

A. General

All available ambient concentration data recorded for BaP and BSO in the vicinity of coke ovens are presented in Appendix A and analyzed in Appendix B. These data (mostly for BaP) have been recorded in 15 locations, some of which contain several coke plants; as a result, approximately one-third of the coke plants are represented. However, in many cases, the data were recorded for only a few days and for only a few sampling stations, thus making exposure estimates based solely upon them unreliable. Moreover, it was necessary to devise some method of predicting ambient concentrations for coke plant areas in which no atmospheric data have been recorded. A procedure for doing this is given here. One approach considered was to model the concentrations mathematically, basing it in part on emission factors, amount of coal processed, and local meteorology. When this approach was tried by the EPA (Youngblood, 1977), it was concluded that, because of the uncertainties in characterizing the sources themselves, definitive estimation of air quality impact of coke ovens by means of dispersion calculations is impossible at this time. The EPA is currently working on developing better emission factors for coke ovens. Because these will not be available for some time, however, it was decided to develop a procedure to extrapolate the available ambient data that have been recorded in the vicinity of coke plants to other locations for which no data has been recorded. When possible and when they seem reliable, the actual recorded ambient concentration data have been used to estimate population exposures.

The procedure that was devised required the following steps, which are described in more detail in subsequent sections of this report:

(1) Information on the type of environmental controls at coke plants is evaluated to determine if facilities can be grouped by their degree of control.

(2) The background concentrations estimated for each coke plant location are those that would exist if the batteries were not in operation.

(3) Existing ambient concentration data are evaluated to determine if atmospheric concentrations can be expressed as a function of distance from the coke plants.

(4) These concentration functions are evaluated to determine if relationships can be derived from them, based on the amount of coal processed and the degree of environmental controls.

(5) The functions are then used to estimate atmospheric concentrations in the vicinity of coke plants, with subsequent estimation of human population exposures.

B. Categorization of Coke Plants by Emission Control

Emission factors are not well-developed for coking operations. Among other factors, they are thought to be a function of process equipment, environmental controls, and operating procedures. In theory, a different set of emission factors exists for each battery. These battery emission factors would be composed of emission factors for such sources as charging, door leaks, pushing, topside leaks, by-product processing, quenching, and the waste gas combustion stack.

The most detailed source of information on coke battery pollution control compliance is based on a survey conducted by PEDCo during September 1974 to April 1975 (Kuliyian, 1976). Among other items reported in this survey was the compliance status of each plant or battery with regard to charging, doors, waste gas combustion stacks, pushing, and quenching. Compliance or noncompliance provide only a general indication of environmental emissions. In addition, some of the batteries have reduced their emissions since 1975. However, this time frame is consistent with the dates when much of the environmental concentration data were recorded.

Weighting factors were assigned to each compliance status listed in the PEDCo survey (in, out, at least one battery out, under a legal plan, undetermined). These weighting factors are based on work performed by EPA personnel, who were familiar with coke operations, to roughly estimate BaP emission factors (Manning, March 18, 1977). This assignment of weights assumes that an in-compliance status indicates low emissions and that an out-compliance status indicates high emissions. Because the EPA work gives emission factors for clean and dirty operations, the clean factor was assigned to the in-compliance status and the dirty factor was assigned to the out-compliance status. Plants having at least one battery out of compliance and at least one battery in compliance were assigned a weighting factor half-way between the out and in factors. These weighting factors are given in Table IV-1. Note that the quenching weighting factors dominate those for all other sources. Individual weights were assigned to each compliance status within plants and summed to give a total for each plant. These sums formed the basis for classifying plants into two groupings. Plants for which no compliance data are available are assigned to a separate group. Plant assignments are shown in Table IV-2. This method of assignment can, and obviously has, led to some misclassifications. At best, it should be regarded as a technique to be used to form strata for statistical sampling. In theory, stratified samples usually have increased precision over simple samples. As will be

Table IV-1

ASSUMED EMISSION WEIGHTING FACTORS
FOR PLANT COMPLIANCE STATUS

Emission Source	Compliance Status				
	In	Out	Undetermined	At Least One Battery Out	Under a Legal Plan
Charging	1.5	80	80	40	40
Doors	16	130	130	73	73
Pushing	N*	3	3	1.5	1.5
Topside**	1.6	65	65	33	33
Quenching	175	350	350	260	260
Waste gas stacks	N	0.7	0.7	0.4	0.4

*N--Negligible.

**Topside compliance was assumed to be the same as door compliance.

Table IV-2

CLASSIFICATION OF COKE PLANTS INTO EMISSION
CATEGORIES (1974-1975)

Plant Number	Classification	Plant Number	Classification	Plant Number	Classification
1*	K**	23	F	45	F
2	F	24	F	46	F
3	K	25	F	47	F
4	K	26	F	48	F
5	F	27	K	49	F
6	F	28	F	50	F
7	F	29	K	51	F
8	F	30	K	52	X
9	F	31	F	53	F
10	F	32	K	54	K
11	F	33	K	55	X
12	K	34	K	56	K
13	F	35	F	57	F
14	F	36	K	58	K
15	F	37	K	59	F
16	F	38	K	60	F
17	K	39	F	61	X
18	X	40	X	62	X
19	K	41	F	63	X
20	K	42	F	64	F
21	K	43	F	65	F
22	F	44	F		

*Plant numbers correspond to plant names given in Table III-3.

**F indicates clean and K indicates dirty. The X indicates that insufficient data were available to classify the plant.

later shown, atmospheric concentration versus distance from the coke plant relationships for the two strata, when scaled for plant production, were different. This indicates that the stratification method did, in this case, provide increased precision.

C. Background Concentrations

Because substances emitted to the atmosphere by coke ovens can also be emitted by other sources, it is necessary to consider atmospheric concentrations as a sum of background plus coke-oven emissions. The coke plants should only be assigned responsibility for their contribution to the total.

Background concentrations are difficult to assess because ambient concentrations are seldom measured in an area when the coke-ovens are not in operation. Moreover, upwind ambient concentrations, recorded near coke plants, appear to have been influenced by the coking operations. In fact, ambient atmospheric concentrations of BaP or BSO have not been measured at all for many of the coke-oven locations. It is therefore necessary to estimate background concentration by using data recorded at a sufficient distance from the coke plant or by using data recorded at "similar" locations. "Similar" cities were taken to be cities in the same general geographic area for which ambient data were available. No attempt was made to select cities based on other factors such as manufacturing. Indeed, this would not have been possible given the paucity of data. Either of these methods has inherent error. In addition, background concentrations have been shown to vary from location to location within a city and with the season (see monitoring data given in Appendix A).

The available BaP atmospheric concentration data for cities without coke plants are given in Appendix A. They were reviewed to identify a "similar" noncoke plant location for each coke plant location. For example, the average BaP concentration over Montgomery, Jacksonville, and Charleston was used to represent Birmingham. The assumed annual average BaP backgrounds are given in Table IV-3. They vary from 0.04 ng/m^3 for Houston to 1.6 ng/m^3 for Pittsburgh.

To illustrate the effects of various assumed background concentrations on exposure estimates, the estimates of population exposures draw on three sets of assumptions. These assumptions are (1) the background concentrations are variable as given in Table IV-3, (2) the background concentration for all locations is 0.4 ng/m^3 (the average for NASN cities without coke ovens shown in Appendix A), and (3) the background concentration for all locations is 1 ng/m^3 (the average for all locations shown in Appendix A).

Table IV-3

ESTIMATED ANNUAL BACKGROUND CONCENTRATIONS
OF BaP FOR COKE PLANT LOCATIONS

Plant Number*	BaP (ng/m^3)	Remarks**
1	0.4	Montgomery, Jacksonville, Charleston
2	0.4	Montgomery, Jacksonville, Charleston
3	0.4	Montgomery, Jacksonville, Charleston
4	0.4	Montgomery, Jacksonville, Charleston
5	0.4	Montgomery, Jacksonville, Charleston
6	0.4	Montgomery, Jacksonville, Charleston
7	0.4	Montgomery, Jacksonville, Charleston
8	1.2	Average of 5 sites in the Los Angeles area
9	0.6	Spokane
10	0.7	Hammond
11	0.7	Hammond
12	0.7	Hammond
13	0.7	Hammond
14	0.7	Hammond
15	0.7	Hammond
16	0.7	Hammond
17	0.7	Hammond
18	0.7	Hammond
19	0.7	Hammond
20	0.7	Hammond
21	0.4	Norfolk, Charleston
22	0.8	Riviera Beach, Maryland
23	1.1	Site 30 km away
24	1.1	Site about 30 km away
25	1.1	Site about 30 km away
26	0.4	NASN site
27	0.3	NASN site
28	0.3	NASN site
29	0.8	Site about 30 km away
30	0.8	Site about 30 km away
31	0.8	Site about 30 km away
32	0.6	Average of Pennsylvania and Ohio sites
33	0.6	Average of Pennsylvania and Ohio sites
34	0.6	Average of Pennsylvania and Ohio sites

Table IV-3 (Concluded)

Plant Number*	BaP (ng/m^3)	Remarks**
35	0.6	Average of Pennsylvania and Ohio sites
36	0.6	Average of Pennsylvania and Ohio sites
37	0.4	NASN site
38	0.5	Site about 12 km away
39	0.6	Average of Pennsylvania and Ohio sites
40	0.6	Average of Pennsylvania and Ohio sites
41	0.8	Average of several Pennsylvania basins
42	0.6	Average of Pennsylvania and Ohio sites
43	0.6	Average of Pennsylvania and Ohio sites
44	0.8	Average of several Pennsylvania basins
45	0.8	Average of several Pennsylvania basins
46	0.8	Average of several Pennsylvania basins
47	0.8	Average of several Pennsylvania basins
48	0.8	Average of several Pennsylvania basins
49	0.8	Average of several Pennsylvania basins
50	1.6	Sites about 10 km away
51	0.8	Average of several Pennsylvania basins
52	0.8	Average of several Pennsylvania basins
53	1.6	Sites about 10 km away
54	1.6	Sites about 10 km away
55	0.8	Average of several Pennsylvania basins
56	0.8	Average of several Pennsylvania basins
57	0.4	Montgomery, Jacksonville, Charleston
58	0.04	Austin and Brownwood
59	0.04	Austin and Brownwood
60	0.5	Sites 20 to 30 km away
61	0.5	Charleston
62	0.5	Charleston
63	0.5	Charleston
64	0.5	Charleston
65	0.7	Hammond

*Plant numbers correspond to plant names given in Table III-3.

**Cities on locations used for reference concentrations.

D. Evaluation of Ambient Concentration Data for Coke Plant Locations

Available ambient data that were recorded in the vicinity of coke plants have been evaluated to determine if it is possible to represent the relationship of concentration mathematically as a function of distance from a coke plant. An analysis of the results of the dispersion calculations performed by EPA (Youngblood, 1977) indicate that such a procedure should be possible. An analysis of data given in Appendix B shows that the BaP atmospheric concentration versus distance relationship about coke plants can be represented by a power function. The procedure taken here is to modify the power function formulation to include allowances for background concentrations and for coke plant capacities. The function selected is as follows:

$$C_d = B + V \cdot A \cdot D^b \qquad (1)$$

where

C_d is the atmospheric BaP at some distance (D) from the coke plant.

B is the location's nominal background concentration.

V is the amount of coal processed annually by the coke plant.

A and B are constants determined by regression.

D is the distance from the plant.

Least squares techniques were used to fit the available data to this function to estimate values for A and b.

To extrapolate these functional representations from areas where data are available to areas where data are not available, it is first necessary to determine if the functional parameters (A and b) are consistent within the emission control grouping given in Table IV-2. If they are found to be consistent within groupings, average values can be used to represent a group. The parameter designated as A in Equation (1) relates to the atmospheric concentration resulting from coke-oven emissions at a distance of 1 km from the plant. It could be estimated for more plants than the slope parameter (b) because of the type of available data.

In the first case evaluated, the background concentrations are assumed to be variable. For five plants representing the better control classification group, the A parameters had an average value of 2.8×10^{-6}, whereas for eight plants representing the poorer control group, the average was 7.3×10^{-6}. Data were insufficient to show a difference in the slope parameter (b) for the two control groupings. The average value for five locations was found to be approximately -1.0. This is consistent with the dispersion modeling data, which gave values of about -0.9 to -1.0 (it is also consistent with standard assumptions sometimes used in diffusion

equations). Hence, this analysis suggests that Equation (1) be used with a value of -1.0 for the parameter b. The value of the parameter A depends on the grouping in which the plant is placed. For the F grouping, a value of 2.8×10^{-6} is used, and for the K grouping a value of 7.3×10^{-6} is used.

A slightly different formulation was derived for the cases in which the background was assumed to be constant for all coke plant locations. The formulation selected is as follows:

$$C_d = VAD^b \quad , \quad \text{if } C_d > \text{assumed background}$$

and C_d = assumed background elsewhere.

The slope parameter b was again assigned a value of -1. The A parameter had an average value of 3.2×10^{-6} for the better control classification group, whereas the average for the poorer control group was 1.3×10^{-5}. These parameter estimates are based on the same coke plants used in estimating the parameters for the variable background model.

Data from only 13 plant locations were used in the development of the models because:

(1) Sufficient data had to be available to develop a concentration-versus-distance function, resulting in the 16 locations shown in Table B-2 of Appendix B.

(2) The data for Duluth and Johnstown were also eliminated from development of the functions because they had much higher concentrations than other plants in the better control grouping. Inclusion of these two plants would greatly increase the population exposure estimates.

(3) The data for Wayne County were also excluded because they could not be related well enough to specific coke plants.

Data for the above locations were, however, used to assist in deriving the location specific exposures.

E. Relationship Between BaP and BSO Atmospheric Concentrations

Because so few data are available for BSO atmospheric concentrations taken in the vicinity of coke production plants, an analysis has been made to determine if the BaP data can be used to predict BSO atmospheric concentrations, that is, to determine if some mathematical relationship exists between BaP and BSO concentrations. Some of the potential hindrances to establishing this type of relationship are that BaP and BSO are emitted from other sources besides coke ovens and that the precise relationship of BSO to BaP for coke-battery emissions is unknown.

The available BSO concentration data (Appendix A) have been plotted against the BaP data on Figure IV-1 for sampling sites that collected both types of data. Average values were used. Data sources included the 1972 NASN urban data, data recorded at sampling sites near coke plants, and Maryland data. The data from the various sources appear to form an increasing function with the cities without coke ovens representing the lower end of the scale and the data recorded near coke plants representing the upper scale. Figure IV-2 is a plot of only more recent data found near the coke plants.

Statistical regression techniques were used to fit mathematical functions to various selected combinations of data given in Figures IV-1 and IV-2. The functional equation used was of the type:

$$BSO = a \cdot BaP^{b} \qquad (2)$$

where

BSO is the atmospheric BSO concentration ($\mu g/m^3$).

BaP is the atmospheric BaP concentration (ng/m^3).

a, b are constants.

The values of the constants were found to be as follows:

Data Set	Parameter a	Parameter b
All data	3.80	0.19
Data for noncoke locations	3.82	0.15
Data for coke locations	2.15	0.53

The regression coefficients (R^2) were found to be around 0.4, indicating a less than good fit to the data. The equations fit to all of the data appear to underestimate the BSO concentrations for the higher BaP concentrations near coke ovens.

Data collected in the occupational environment should provide a better estimate of the relationship between BaP and BSO emitted by coke ovens than do environmental data; the concentrations are much higher and have not yet been diluted or mixed in the environment. From June 1971 to January 1972, Schulte et al. (1975) collected and analyzed 1,440 airborne samples from within five coke-oven facilities. Their raw data are not presented; however, they state that the data collected on the high-volume filters (similar to those used in ambient sampling) were fairly consistent. The weight of the BSO extract was generally 20%-40% of the weight of the entire sample, and the weight of the BaP was 1% of the BSO extract.

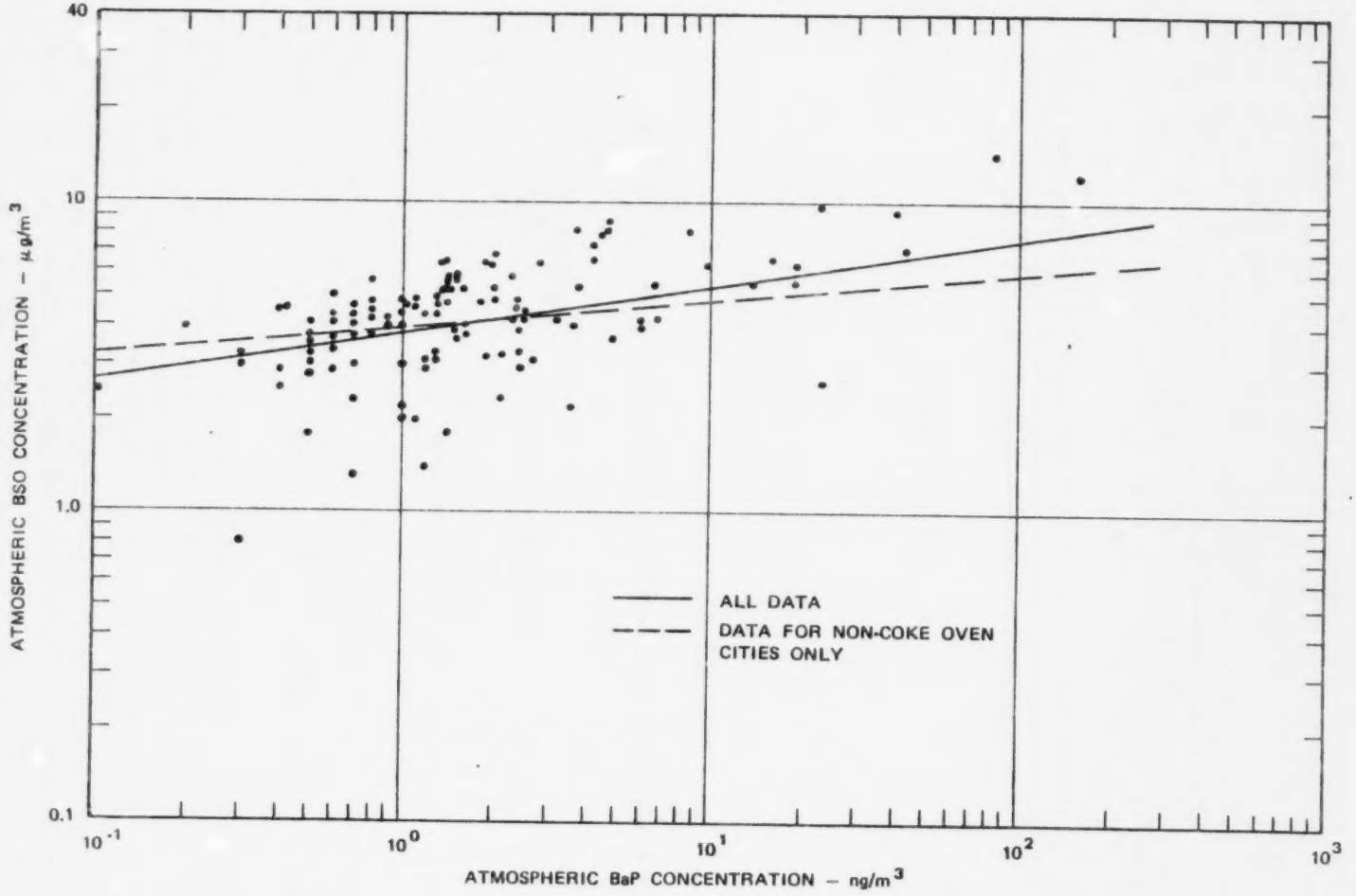


FIGURE IV-1. RELATIONSHIP BETWEEN BSO AND BaP ATMOSPHERIC CONCENTRATIONS FOR ALL LOCATIONS

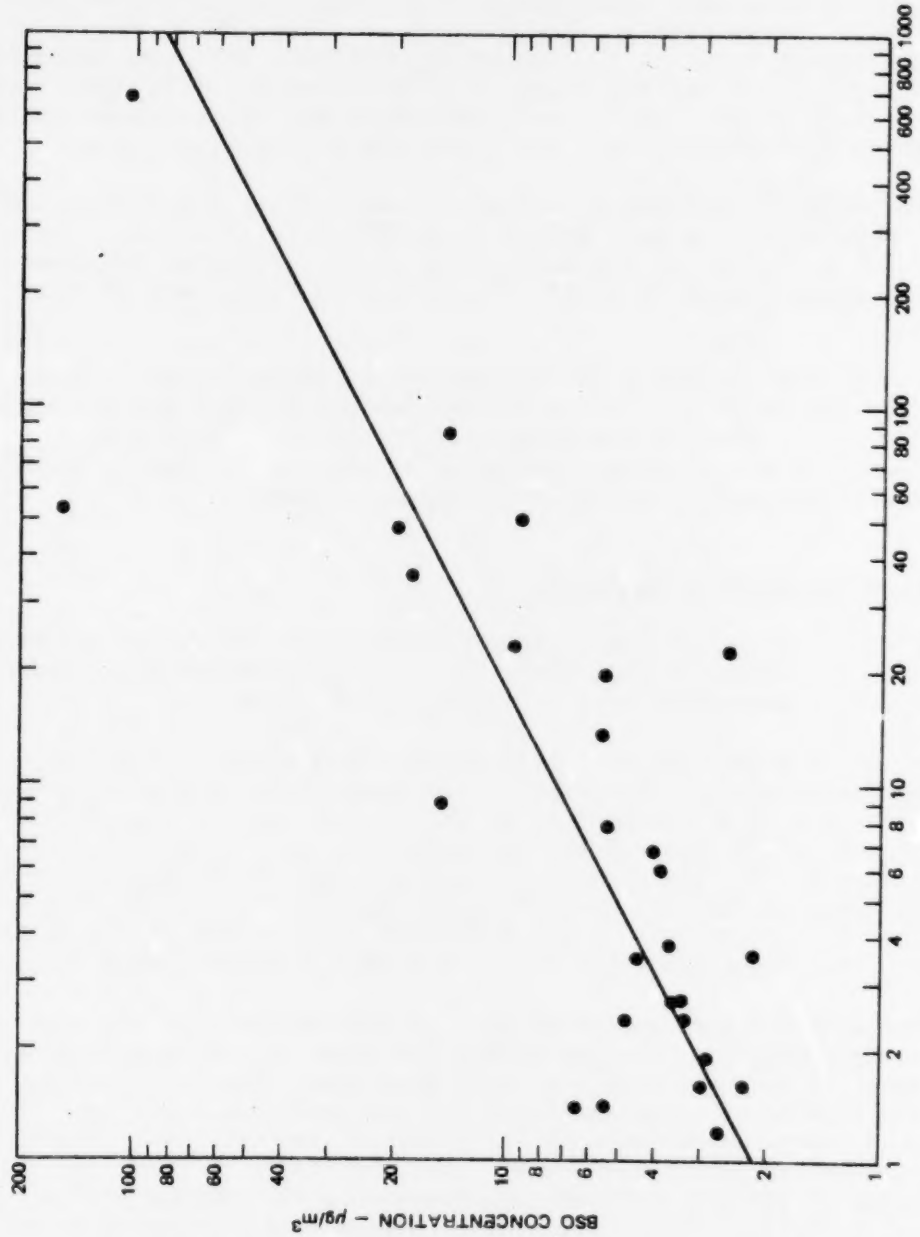


FIGURE IV-2. RELATIONSHIP BETWEEN BaP AND BSO CONCENTRATIONS FOR LOCATIONS NEAR COKE OVENS

Smith (1971) presents BaP and BSO data for 14 airborne samples collected on the platform of the larry car inside a coke-oven battery. These data are plotted in Figure IV-3. Antell (1977) supplied BaP and BSO data on 12 additional occupational airborne samples collected during 1974 and 1975. These data are also plotted on Figure IV-3. A statistical t-test shows that, based on the data given in Figure IV-3, the assumption that the BaP is 1% of the BSO cannot be rejected at the 0.05 significance level. No statistically significant difference was found between the BaP versus BSO relationships in the Smith data and in the Antell data.

Differences between the actual BSO concentrations and predicted BSO concentrations (assuming that BaP is 1% of BSO) were evaluated. The one-standard deviation between the differences in the predicted and observed concentrations was found to be 53% for individual values and 10% for the mean.

The indicated procedure for estimating BSO exposures is first to estimate BaP exposures due solely to coke ovens. The BSO exposures are made assuming that the BaP constitutes 1% of the BSO. This procedure clearly includes all the error present in estimating BaP exposures, plus an additional source of error in relating BSO to BaP.

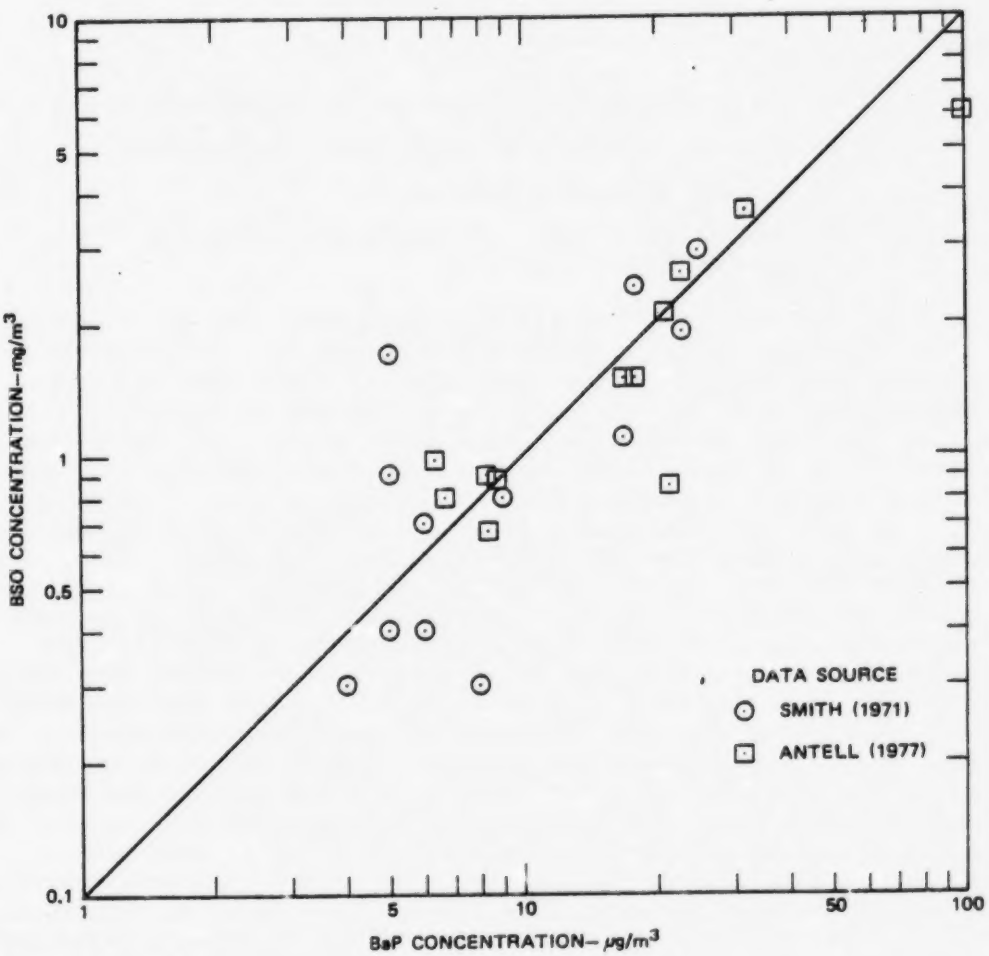
F. Population Exposure Estimates

The estimated population exposures to coke-oven emissions are given in the summary section of this report and are not repeated here. However, a general discussion of the approach is included.

Resident populations were estimated for five concentric geographic rings about each plant. The radii of the rings were taken as 0 to 0.5, 0.5 to 1, 1 to 3, 3 to 7, and 7 to 15 km. These spacings were selected to correspond to the shape of the concentration versus distance curves shown in Appendix B. Resident population for each of the geographic rings was obtained from the Urban Decision Systems, Inc., Area Scan Report, a computer data system that contains the 1970 census data in the smallest geographic area available (city blocks and census enumeration districts).

Average annual BaP concentrations for each geographic ring were estimated by using the empirical models for those coke plants for which questionable or no monitoring data were available. The concentration at 0.4 km was used to estimate exposures for the innermost ring. For the other rings, the concentration at the center of each ring was selected as the exposure concentration for all people residing in that ring. The center point is the radius which best represents the average population exposures in the geographic ring when a uniform ring population density and decay slope of -1 are assumed. That is, when

$$\int_{R_1}^{R_c}\int_{o}^{2\pi} \mathrm{RVAR}^{-1} f\,d\theta\,dR = \int_{R_c}^{R_2}\int_{o}^{2\pi} \mathrm{RVAR}^{-1} f\,d\theta\,dR$$



Note: TWO OF SMITHS DATA POINTS CANNOT BE SHOWN ON THIS FIGURE. BOTH HAVE BaP=4 $\mu g/m^3$ AND BSO= 0.0 mg/m^3.

FIGURE IV-3. RELATIONSHIP BETWEEN BaP AND BSO AIRBORNE CONCENTRATIONS FOR OCCUPATIONAL COKE OVEN LOCATIONS

solving this equation gives:

$$R_c = \frac{(R_2 + R_1)}{2}$$

where

V, A are as previously defined in the exposure equations

R_2, R_1 are ring outside and inside radii respectively

f is ring population density

R_c is the radius where the exposures inside and outside R_c are equal.

The models were used for 45 of the 65 coke plants. The plant-specific, best fit equations given in Appendix B were used for locations for which sufficient monitoring data were available. On a few locations, the monitoring data were used to fix the concentration at a related distance from the plant and the empirical model--slope of -1.0 was used to estimate concentrations at other distances. In all, some monitoring data were used in making exposure estimates for 20 of the coke plants. In addition, monitoring data were used to estimate the concentration of the outermost population ring about the Fairfield plant near Birmingham. Thus, some monitoring data were used in estimating the exposures for 21 coke plants. Available monitoring data were not used for an additional seven coke-plant exposures for the following reasons: The monitoring stations were situated too far from the Woodward, Thomas, Fairless Hills, Alan Wood, and Chattanooga coke plants to provide useful exposure data for nearby residential populations. The Philadelphia monitoring data were not used because they are reported as having been upwind of the plant during collection and are much lower than indicated by the NASN data or the Pennsylvania monitoring data. The Houston data were not used because they appear to be questionably low for the city, even if it had no coke plant. According to AISI (1978), "Houston is a large industrial and transportation center involved in petrochemical operations--which are important sources of BaP and benzene solubles--in addition to being a major port." For locations with more than one coke plant, the exposures were estimated for overlaps of the geographic rings. To make these estimates, the geographic rings about the various coke plants in the area were drawn to scale. The BaP concentrations for the overlaps was the sum of the concentrations for the various coke plants. The population of the overlaps was based on the area contained in the overlaps and the ring populations.

Concentration subgroups were then developed, based on the range of concentrations for the estimated exposures, and the total number of residents for each exposure subgroup were calculated. The population residing within a subgroup was excluded if its average annual BaP concentration due only to coke-oven emissions was less than 0.2 ng/m^3. These subgroupings were made for exposures to coke-oven emissions only and to coke-oven emissions plus background concentrations.

Population exposures to BSO were calculated using the procedure given in Section IV-E. This procedure estimates BSO exposures based on estimated BaP exposures.

Appendix A

AMBIENT ATMOSPHERIC BaP AND BSO CONCENTRATIONS

Appendix A

AMBIENT ATMOSPHERIC BaP AND BSO CONCENTRATIONS

A. General

This appendix presents BaP and BSO atmospheric concentration data recorded in the vicinities of coke manufacturing plants. Data are also presented that give background concentrations for locations that contain and do not contain coke ovens. Most of the data given is based on 24-hr samples; however, some are based on monthly or quarterly composites. Unless otherwise specified, sample size refers to the number of 24-hr days of data available. All data used in this report are based on high-volume filter samples. In addition, many of the sampling programs were conducted over a relatively few days within 1 or 2 consecutive months; thus, they may not be entirely representative of an area's average annual concentration. The implications of this sampling approach in estimating population exposures is described in further detail in Appendix B.

B. Atmospheric BaP and BSO Concentration Data Recorded Near Coke Manufacturers

Atmospheric data that have been recorded near coke manufacturers are described in the following paragraphs.

1. Monessen Area Air Quality Study, Pennsylvania

The Pennsylvania Department of Environmental Resources conducted an air quality study to determine the distribution and magnitude of total suspended particulates (TSP), benzene soluble organics (BSO), and benzo-(a)pyrene (BaP) concentrations in the Monessen area. The impact and extent of air pollution due to sources at the Wheeling-Pittsburgh Steel Corporation, Monessen, were evaluated, with sampling conducted from April 6 to June 21, 1976, at three sites near the steel plant. Meteorological and selective sector actuator techniques were included in the sampling program (DER, 1977A).

A statistical summary of the data for the three sites is given in Table A-1. The average TSP concentrations ranged from 79 to 166 $\mu g/m^3$, average BaP concentrations from 2.7 to 40.8 ng/m^3, and the average BSO from 2.6 to 9.2 $\mu g/m^3$. Selective sector actuator sampling and a concentration-wind direction frequency weighting technique all confirmed that the steel plant is the major source of TSP and BaP. The average concentrations found in areas in the direction of winds coming from the

Table A-1

MONESSEN AIR STUDY, 24-HOUR SAMPLE CHARACTERISTICS

	Sample Size	Average	Range	Geometric Mean	Geometric Standard Deviation
TSP ($\mu g/m^3$)					
Station 2	29	166.0	27.0-360.0	145.0	1.76
Station 6	28	79.0	22.0-165.0	71.0	1.64
Station 7	31	113.0	26.0-300.0	93.0	1.91
BaP (ng/m^3)					
Station 2	29	40.8	0.3-206.4	10.0	7.60
Station 6	28	2.7	0.2-10.8	1.6	2.78
Station 7	31	22.8	0.4-100.3	10.1	4.57
BSO ($\mu g/m^3$)					
Station 2	29	9.2	1.5-25.4	6.5	2.34
Station 6	28	3.3	0.6-9.1	2.6	2.01
Station 7	31	2.6	0.9-19.3	3.8	2.36

Station 2 is 1 km ESE of the coke ovens.
Station 6 is 2.1 km NW of the coke ovens.
Station 7 is 1.8 km ENE of the coke ovens.

Source: DER (1977A)

plant are between 1.5 and 3 times the average concentrations for winds from all other directions (DER, 1977A).

2. Allegheny County, Pennsylvania

Three coke batteries are located in Allegheny County: U.S. Steel Corporation in Clairton, Jones and Laughlin in Hazelwood, and Sherango, Inc. on Nevell Island. From April to September 1976, high-volume particulate samples taken from 11 sites were analyzed for BaP. The sampling schedule included two 10-week periods of four and two samples per week, respectively (Ek, 1977).

Table A-2 shows the results obtained during the sampling. The average BaP concentrations for the 11 locations varied between 1.64 and 51.95 ng/m^3. Eight additional samples were collected during first-stage alerts at Liberty Borough in April and June 1976. Four were collected over 24 hours and four over 8 to 12 hours. These data which are given

Table A-2

AMBIENT BaP CONCENTRATIONS FOR ALLEGHENY COUNTY, PENNSYLVANIA

(ng/m3)

Site Number	Site Location*	Sample Size	Average	Range
7102	10.5 km N of USS, 8 km E of J&L, 21.5 km SE of S	2	1.64	0.2- 3.1
5702	18 km NW of USS, 4.5 km N of J&L, 12 km ESE of S	2	2.62	0.3- 4.9
8601	0.5 km SE of USS, 14 km SE of J&L, 28 km SE of S	6	13.63	0.9- 67.7
8704	2.0 km NE of USS, 12 km SE of J&L, 27 km SE of S	5	15.00	0.3- 40.4
5802	18 km NW of USS, 6 km NW of J&L, 10 km SW of S	2	2.29	1.8- 2.8
7570	8.5 km NNE of USS, 9.5 km ESE of J&L, 24 km SE of S	5	6.12	0.9- 20.1
8602	1.5 km NNW of USS, 12 km SE of J&L, 26 km SE of S	4	28.17	2.8- 83.5
6903	12 km NW of USS, 1 km SSE of J&L, 16 km SE of S	10	3.95	0.5- 19.0
8790	2 km NE of USS, 13 km SE of J&L, 27.5 km SE of S	20	51.95	0.4-310.0
5602	16 km NNW of USS, 5 km NNE of J&L, 15 km ESE of S	2	3.78	3.1- 4.5
7004	12.5 km N of USS, 6 km E of J&L, 18.5 km SE of S	2	1.66	1.4- 1.9

*USS is U.S. Steel, J&L is Jones and Laughlin, and S is Shenango.

Source: Ek (1977)

in Table A-3, show average BaP concentrations about six times higher than for the regular sampling given in Table A-2.

Table A-3

BaP DATA OBTAINED DURING FIRST STAGE ALERTS AT LIBERTY BOROUGH--SITE 8790
(ng/m^3)

Sample Number	24-Hour Data	8-12 Hour Data
1	427.9	405.8
2	277.8	458.8
3	320.4	189.8
4	171.0	155.6
Average	299.3	302.3

3. Geneva Works, Utah

The data collected during October and November 1976 for BaP concentrations near the U.S. Steel Geneva Works located near Provo, Utah, are summarized in Table A-4. Eight stations within 4 km of the coke batteries showed average BaP concentrations of 1.47 to 3.81 ng/m^3. Two background stations 20 to 30 km away showed average BaP concentrations of 0.12 and 0.83 ng/m^3.

4. Wayne County, Michigan

Three companies operating coke batteries are located at Wayne County, Michigan: Solvay, Ford, and Great Lakes Steel. Ambient atmospheric BaP concentration data were reported annually for seven sites in the general area for 1971 to 1975 and are given in Table A-5. Annual BaP concentrations for the various sites varied between 0.34 to 14.72 ng/m^3.

5. Buffalo, New York

Three companies operate coke batteries near Buffalo, New York: Semet-Solvay, Bethlehem Steel, and Donner-Hanna. Atmospheric BaP concentration data were recorded from 1973 to 1974 on 13 sites, in addition to data recorded at the National Air Surveillance Network (NASN) site. These data, which are given in Table A-6, indicate the average BaP concentrations ranged from 0.45 to 27.10 ng/m^3.

Table A-4

ATMOSPHERIC BaP CONCENTRATIONS NEAR THE GENEVA WORKS IN UTAH
(ng/m^3)

Station Number	Location in Relation to Battery	Sample Size	Average	Range
1	2.0 km NW	9	2.08	0.40-4.42
2	2.7 km NW	6	3.81	2.52-5.27
3	2.4 km NW	9	3.15	0.97-6.30
4	1.8 km N	11	2.41	0.44-5.85
5	1.3 km NE	11	3.13	0.54-6.29
6	2.4 km SE	11	1.63	0.46-3.44
7	4.0 km NW	3	2.10	0.87-3.53
8	2.6 km S	11	1.47	0.38-3.35
9	30.0 km S	11	0.12	0.01-0.32
10	20.0 km N	9	0.83	0.05-2.77

Table A-5

AMBIENT BaP CONCENTRATIONS FOR WAYNE COUNTY, MICHIGAN
(ng/m^3)

Site Number	1971	1972	1973	1974	1975	Average
02	3.00	2.44	3.02	1.46	3.43	2.67
04	2.97	3.14	4.16	1.70	4.85	3.36
05	9.32	5.95	11.78	10.83	14.72	10.52
06	3.62	2.62	3.12	0.52	1.47	2.27
08	2.39	2.56	2.70	0.44	2.54	2.13
11	1.30	1.32	2.00	0.34	0.73	1.14
NASN	1.40	1.90	1.00	--	1.00	1.33

No. 2 is 14 km NE of Solvay, 14.5 km NE of G.L.*, and 18 km ENE of Ford
No. 4 is 7.2 km NNE of Solvay, 9.3 km NE of G.L., and 9 km NE of Ford.
No. 5 is 1.6 km N of Solvay, 4 km NNE of G.L., and 4.4 km E of Ford.
No. 6 is 15.3 km NNW of Solvay, 16.5 km NNW of G.L., and 11.7 km NNW of Ford.
No. 8 is 10.5 km SW of Solvay, 8.5 km SW of G.L., and 9.3 km SSW of Ford.
No. 11 is 30 km SW of Solvay, 29 km SW of G.L., and 30 km SW of Ford.

*G.L. - Great Lakes Steel.

Table A-6

AMBIENT BaP CONCENTRATIONS FOR BUFFALO, NEW YORK

Site Number	Site Location	Sample Size	Average	Range
1	3.1 km E of Beth. and 3.4 km SE of D-H*	37	5.99	0.27-30.5
2	1.9 km ESE of Beth. and 3.8 km S of D-H	81	8.99	0.26-48.7
3	3.8 km NE of Beth. and 1.5 km SE of D-H	48	11.38	0.06-68.4
4	1 km ENE of Beth. and 2.8 km S of D-H	7	27.10	2.76-48.8
5	3 km N of Beth. and 1.4 km WNW of D-H	78	2.78	0.05-23.8
6	4.3 km NE of Beth. and 1.1 km ENE of D-H	65	9.10	0.20-65.6
7	5.6 km NE of Beth. and 2.1 km NNE of D-H	41	7.29	0.07-46.2
8	0.6 km W of Allied	73	1.29	0.05-21.2
9	1.2 km ESE of Allied	76	3.80	0.13-81.4
10	2.4 km NE of Allied	44	3.74	0.01- 9.3
11	30 km SW of Beth. and 34 km SW of D-H	44	0.82	0.04-24.5
12	3.2 km NW of Allied	28	0.45	0.06- 3.1
13	4 km SW of Beth. and 6.2 km S of D-H	7	1.29	0.40- 3.7
NASN	8.8 km NNW of Beth. and 5.6 km N of D-H	--	0.70**	--

*Beth. is Bethlehem Steel; D-H is Donner-Hanna.

**Two-year composite

6. Duluth, Minnesota

Thirty-eight samples for ambient BaP concentrations were obtained during the period of January 1974 to November 1975 from two sites within 3 km of the U.S. Steel coke batteries in Duluth, Minnesota. These data are summarized in Table A-7. Average BaP concentrations of 0.22 and 1.45 ng/m^3 were found for the two sites. When most of the samples were collected, the wind was blowing in the general direction of the collection sites from the plant.

Table A-7

AMBIENT BaP CONCENTRATIONS FOR DULUTH, MINNESOTA
(ng/m^3)

Site Number	Distance from Coke Ovens	Sample Size	Average	Range
1	2.1 km SW	18	1.45	BDM-7.02*
2	2.7 km N	20	0.22	BDM-1.25

*BDM - below detectable minimum.

Source: Jungers (1977A).

7. Gadsden, Alabama

The Republic Steel Corporation operates coke ovens in Gadsden, Alabama. Atmospheric BaP concentrations were sampled at two sites within 1.6 km of the coke ovens during 1974, 1975, and 1976. The data from this sampling which are summarized in Table A-8, indicate the annual atmospheric BaP concentrations varied from 0.44 to 5.06 ng/m^3.

8. Birmingham, Alabama, Area

Five coke battery facilities, which are within about 20 km of Birmingham, are located at Tarrant, Woodward, Thomas, Birmingham, and Fairfield. Atmospheric BaP concentrations were sampled at Tarrant and Fairfield during 1976, and NASN data are available for Birmingham. These data are given in Table A-9. The average BaP concentrations ranged from 2.5 to 4.5 ng/m^3. BaP data were also recorded for five CHAMP sites in the Birmingham area. These data are given in Table A-10.

Table A-8

AMBIENT BaP CONCENTRATIONS FOR GADSDEN, ALABAMA
(ng/m3)

Site Number	Distance from Coke Ovens	Average Concentrations*			
		1974	1975	1976	3-Year
1	1.6 km E	5.06(0.44)**	0.75	0.58	2.13(0.60)**
2	1.1 km SW	0.97	0.44	1.89	1.10
NASN	Same as Station 1	0.50	0.60	--	0.55

*Sample size for each year for Sites 1 and 2 was 5 days.

**Excludes one high observation of 23.55 ng/m^3.

Source: Jungers (1977B).

Table A-9

AMBIENT BaP CONCENTRATIONS FOR BIRMINGHAM, ALABAMA
(ng/m^3)

Site Number	Distance from Coke Plants	Sample Size	Average	Range
1	Tarrant (0.5 km NW)	2	4.46	0.06-8.86
2	Fairfield (0.5 km ESE)	3	2.79	1.10-5.31
NASN*		-	2.50	--

*1974 sample composite.

Source: Jungers (1977B).

Table A-10

CHAMP SITE AMBIENT ATMOSPHERIC BaP DATA FOR THE BIRMINGHAM AREA (1975 Data)

Site Number	Distance from Batteries (km)			Sample Size*	BaP (ng/m^3)	
	Fairfield	Birmingham	Tarrant		Average	Range
304	11.4	3.8	2.4	6	4.2	0.7-9.2
305	25.8	5.0	13.0	12	1.8	0.6-3.7
306	10.3	10.8	13.4	12	1.5	0.4-4.0
307	4.9	18.4	21.4	6	2.4	0.9-4.3
323	16.4	2.4	1.9	12	2.9	1.2-6.6
331	13.4	3.2	5.4	12	3.5	1.4-5.5

*Number of months for which data are available; for individual months data were generally collected for 25 to 31 days.

9. Johnstown Air Basin, Pennsylvania

Two coke plants are located near Johnstown, Pennsylvania (Bethlehem Steel's Franklin and Rosedale Divisions). An air quality study was conducted from August through November 1975 to determine the distribution and magnitude of TSP, BSO, and BaP concentrations in the Johnstown area. Concentration data were obtained for eight sampling sites 0.6 to 7.8 km from the Franklin Works (Table A-11). BaP concentrations ranged from 85.3 ng/m^3 for the site nearest the Franklin plant to 3.6 ng/m^3 for the site farthest from the plant.

Wind-actuated sampling was also conducted for TSP, BSO, and BaP. For all three, in-sector sample concentrations were almost double the out-sector concentratio[illegible].

10. Philadelphia, Pennsylvania

One coke facility is situated in Philadelphia (Philadelphia Coke Division), and another two coke facilities are within 12 km of the city at Alan Wood and Fairless Hills. Air quality data were collected at four different times from November 1976 to January 1977 to determine

Table A-11

AMBIENT BaP, BSO, AND TSP CONCENTRATIONS FOR JOHNSTOWN, PENNSYLVANIA

Site Number	Distance from Franklin Coke Ovens	Number of Samples	BaP (ng/m^3) Average	BaP (ng/m^3) Range	Average ($\mu g/m^3$) TSP*	Average ($\mu g/m^3$) BSO
1	7.8 km WSW	30	3.6	0.5- 15.4	32	2.2
2	3.8 km W	32	13.8	2.0-110.9	70	5.5
3	2.9 km SW	33	7.7	0.9- 41.8	71	5.4
4	1.0 km NNE	32	23.4	3.6-246.6	142	9.7
5	4.6 km SSW	28	6.0	1.5- 11.0	55	3.9
6	3.4 km SSW	31	6.8	1.4- 24.5	58	4.1
7	0.6 km ESE	34	85.3	1.5-575.9	179	14.1
8	1.9 km SE	31	19.9	1.2-102.9	70	5.6

*Geometric mean.

Source: DER (1977B).

the distribution and magnitude of TSP, BSO, and BaP in Philadelphia. Concentration data were obtained for 13 sampling stations about 2 to 14 km from Philadelphia Coke Division. These data are summarized in Table A-12. The average BaP concentrations for the 13 sampling sites ranged from 0.97 to 4.70 ng/m^3. BSO average concentrations ranged from 3.05 to 8.56 $\mu g/m^3$.

11. Granite City, Illinois

BaP was measured at eight sampling sites during March to May 1975 between 0.5 to 3.5 km from the National Steel coke ovens in Granite City, Illinois. The data obtained during this sampling, which are summarized in Table A-13, indicate that average atmospheric BaP concentrations for the stations ranged from 2.6 to 12.2 ng/m^3.

More recently TSP, BSO, and BaP data have been obtained for 3 days on two sites within 0.8 km of the coke batteries (Table A-14). BaP measurements from individual observations ranged from 1.6 to 278 ng/m^3.

12. Houston, Texas

Atmospheric BaP samples were obtained from seven sites located up to 5.5 km from the Armco Steel coke ovens situated in Houston, Texas. Samples were recorded at various times from 1973 to 1976. The data summarized in Table A-15 show that average concentrations by site varied from 0.03 to 0.28 ng/m^3. These concentrations are much lower than those recorded at similar distances from other coke-oven locations, perhaps indicating any of the following factors:

- Good emission control.
- Faulty measurement techniques.
- All samples recorded upwind.
- Ovens not in operation when measurements were recorded.

13. Cleveland, Ohio

King et al. (1976) have reported on atmospheric BaP concentrations for a number of sites in Cleveland, Ohio. These data are summarized in Table A-16. The geometric means are given rather than the arithmetic means.

14. Sparrows Point, Maryland

The Maryland State Division of Air Quality Control measures ambient BaP and BSO concentrations for many sites within the state, four of which are located within approximately 12 km of the coke batteries. Data for 1976 are given in Table A-17.

Table A-12

AMBIENT BaP, BSO, AND TSP CONCENTRATIONS FOR PHILADELPHIA, PENNSYLVANIA

Site Number	Location from Philadelphia Coke Ovens	Number of Samples	BaP (ng/m^3)		Average ($\mu g/m^3$)	
			Average	Range	TSP	BSO
1	14.1 km SW	4	3.82	2.09-8.81	76.5	5.44
2	3.5 km SW	3	1.61	0.82-2.26	130.5	4.00
3	19 km SW	4	2.27	1.09-5.35	102.5	5.75
4	12.5 km WSW	4	0.97	0.21-1.81	44.8	3.05
5	13.7 km WNW	4	1.34	0.35-2.31	36.3	3.11
6	9.3 km NNE	4	2.54	1.38-4.53	48.0	4.15
7	5.8 km w	4	4.24	1.90-6.29	85.5	7.22
8	10 km SW	4	1.96	1.38-2.31	60.3	4.77
9	2 km WNW	4	2.78	1.26-4.46	60.0	6.42
10	8.8 km SW	4	4.42	2.28-7.15	109.7	7.76
11	13 km SSW	3	3.68	1.55-6.70	133.3	8.05
12	10 km SW	3	4.70	2.44-8.06	95.0	8.56
13	5.2 km SW	4	4.10	1.57-9.90	102.3	6.59
NASN	--	-	2.10	-	-	4.66

Source: Lazenka (1977).

Table A-13

AMBIENT BaP CONCENTRATIONS FOR GRANITE CITY, ILLINOIS
(ng/m^3)

Site Number	Distance from Coke Ovens	Sample Size	Average	Range
LN1	0.7 km N	3	8.60	1.1-16.5
NW2	0.6 km SSW	3	4.83	0.6-9.5
008	1.1 km NE	2	2.65	1.8-3.5
006	2.4 km WNW	2	8.15	8.0-8.3
007	1.8 km NW	2	5.20	3.9-6.5
009	1.5 km W	1	3.50	--
010	3.5 km WNW	2	12.15	1.8-22.5
011	2.9 km WSW	2	7.15	3.9-10.4

Table A-14

ADDITIONAL ATMOSPHERIC AMBIENT DATA FOR GRANITE CITY, ILLINOIS

Station	Distance from Coke Ovens	Pollutant	Day 1	Day 2	Day 3	Average
1	0.8 km N	TSP ($\mu g/m^3$)	113	344	268	238
		BSO ($\mu g/m^3$)	4.9	18	14	12
		BaP (ng/m^3)	2.1	278	202	161
2	0.5 km S	TSP ($\mu g/m^3$)	193	113	83	130
		BSO ($\mu g/m^3$)	17	4.2	0.5	7
		BaP (ng/m^3)	124	2.6	1.6	43

Table A-15

AMBIENT BaP CONCENTRATIONS FOR HOUSTON, TEXAS
(ng/m^3)

Site Number	Distance from Coke Ovens	Sample Size	Average	Range
256034	1.0 km NW	6	0.17	0.05-0.62
256015	0.9 km NNW	5	0.15	0.07-0.35
233006	2.2 km NE	4	0.05	0.02-0.11
256017	0.8 km W	6	0.03	0.02-0.05
256019	2.2 km WSW	4	0.33	0.04-1.00
256028	0.8 km SSE	7	0.28	0.05-0.34
256005	5.4 km SW	1	0.16	--

Table A-16

AMBIENT BaP CONCENTRATIONS FOR CLEVELAND, OHIO

Site Number	Location from Coke Battery*	Sample Size	BaP (ng/m^3) Geometric Mean**	BaP (ng/m^3) Maximum
1	0.8 km N	21	1.40	41.0
3	4.8 km SW	37	0.62	3.1
4	4.4 km NE	23	0.64	15.0
5	4.4 km SE	28	0.58	3.3
6	12.0 km NE	22	0.71	3.0
7	7.2 km W	38	0.46	2.1
8	6.8 km SW	28	0.44	2.3
9	1.0 km SE	30	3.60	130.0
10	6.0 km NNE	33	0.74	7.2
12	13.2 km ESE	32	0.43	2.0
13	4.4 km S	23	0.85	14.0
14	9.6 km SE	22	0.47	3.7
15	3.2 km W	21	0.51	3.5
17	6.4 km NE	32	0.91	49.0
20	16.8 km NE	19	0.50	6.9
21	4.0 km NNW	22	1.10	17.0

*Locations are only approximate.

**Arithmetic mean not reported.

Source: King et al. (1976)

Table A-17

AMBIENT ATMOSPHERIC BaP AND BSO CONCENTRATIONS FOR SPARROWS POINT, MARYLAND

Distance from Coke Batteries*	Sample Size**	BaP (ng/m^3) Average	BaP (ng/m^3) Range	BSO ($\mu g/m^3$) Average	BSO ($\mu g/m^3$) Range
12 km N	2	1.4	1.1-1.7	6.5	6.3-6.8
7 km NNW	12	1.4	0.2-4.4	5.4	3.0-8.0
3 km W	10	1.9	0.1-2.6	--	--
4 km SSW	10	2.4	0.4-5.4	4.8	2.6-8.7

*Locations are only approximate.

**Number of months for which data are available.

15. Chattanooga, Tennessee

As part of the CHESS and CHAMP programs, BaP samples were collected for nine sites in the Chattanooga area. These data for 1975 are summarized in Table A-18.

Table A-18

AMBIENT BaP AND BSO CONCENTRATIONS FOR CHATTANOOGA, TENNESSEE

Site Number	Distance from Coke Ovens	Number of Samples*	BaP (ng/m^3) Mean	BaP (ng/m^3) Range	BSO ($\mu g/m^3$) Mean	BSO ($\mu g/m^3$) Range
621	7.6 km	12	3.83	1.0-8.4	3.69	2.2-6.5
622	8.9 km	12	3.49	0.4-8.5	4.51	2.6-9.1
631	20.2 km	12	1.63	0.2-3.6	3.04	1.4-5.2
632	15.2 km	12	1.85	0.2-5.9	2.93	1.1-6.4
633	16.4 km	12	1.55	0.1-4.2	2.33	0.6-4.6
634	23.8 km	12	0.82	0.0-2.7	1.73	0.3-2.7
635	14.3 km	12	1.23	0.1-3.0	2.66	1.5-4.1
641	13.0 km	10	2.35	0.2-8.6	3.26	1.8-5.3
642	15.1 km	12	2.66	0.2-5.6	3.60	1.5-7.0

*Number of months for which data are available; for individual months data were generally collected for 20 to 31 days.

C. Ambient Background BaP and BSO Concentration Data

Because coke ovens are not the only sources of BaP and BSO concentrations in the atmosphere, the coke-oven contributions must be placed in perspective with each area's nominal background concentrations. Data are presented here for ambient background concentrations measured in cities in which coke ovens are located, cities without coke ovens, and remote rural areas.

1. NASN Air Quality System Data

NASN routinely monitors suspended particulate concentration levels in urban and nonurban areas, generally reporting them as quarterly

composites for stations in the network. The composite, which pools all samples collected during the quarter, assists in generating sufficient material for laboratory analysis.

Before 1971, BaP analysis was made for more than 120 sites per year. For 1971 and subsequent years, the sites were limited to 40 because of time and resource restrictions. These 40 sites were selected to update BaP concentrations in cities with and without coke ovens. Three sites were selected in National Parks to provide nonurban background readings (U.S. EPA, 1974).

Annual average BaP concentrations for 1967 to 1976 are given in Table A-19 for the 40 NASN sites. Table A-20 gives BSO data recorded at these sites for 1971 and 1972. The BaP and BSO concentrations are summarized in Table A-21. The BaP concentrations are generally less than 0.1 ng/m^3 for rural locations. Most urban locations without coke ovens have average concentrations of less than 1 ng/m^3 (the average is 0.38 ng/m^3); however, areas with coke ovens generally have average concentrations in excess of 1 ng/m^3 with Ashland's 4.7 ng/m^3 the highest and Dearborn's 3.1 ng/m^3 the next highest. Coke ovens are located in both Ashland and Dearborn. The overall average for cities with coke ovens is 1.21 ng/m^3. The concentrations for coke-oven cities are significantly higher than for the noncoke-oven cities at the 0.01 significance level.

The BSO concentrations were generally less than 5 $\mu g/m^3$. The average concentrations of most urban locations range from 1 to 4 $\mu g/m^3$. Ashland, Chattanooga, Pittsburgh, Buffalo, and Hammond have concentrations exceeding 5 $\mu g/m^3$. The concentrations for the coke-oven and noncoke-oven cities are not significantly different at the 0.05 level.

Table A-22 shows the change from 1966 to 1976 in BaP concentrations in the atmosphere for cities with and without coke ovens. Both classes of cities have shown a reduction; however, the average difference between the two types of cities has been fairly constant since 1968. The decrease in concentrations is statistically significant at the 0.01 level for both coke-oven and noncoke-oven cities. Both coke- and noncoke-oven cities have shown an average BaP reduction of 9% per year over the last 9 years.

2. Pennsylvania Air Quality System

The Pennsylvania Division of Technical Services and Monitoring, Bureau of Air Quality and Noise Control has systematically surveyed air quality since 1970. As part of this program, the division monitors suspended and settleable particulates at 91 locations. Suspended particulates are collected on a glass fiber filter with a high-volume air sampler. Each sample represents the particulate matter filtered from approximately 2000 m^3 of air over 24 hours. Samples are taken from midnight to midnight every 6 days (DER, 1977).

Table A-19

ANNUAL AVERAGE AMBIENT BaP CONCENTRATIONS AT NASN URBAN STATIONS
(ng/m^3)

Location	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Montgomery, AL	2.3	2.9	2.0	1.3	0.5	0.5	0.3	0.4	0.3	0.3
Chicago, IL	3.0	3.1	3.9	2.0	2.5	1.3	0.4	--	1.0	0.5
Detroit, MN	5.4	5.1	3.9	2.6	1.4	1.9	1.0	--	1.0	1.1
New York, NY	3.9	--	3.6	3.0	2.3	1.8	0.7	0.9	0.9	0.5
Toledo, OH	1.9	1.8	1.5	1.4	0.8	0.4	0.4	0.2	0.4	0.5
Philadelphia, PA	5.9	2.9	4.0	2.4	2.3	0.9	0.6	0.8	0.6	1.0
Pittsburgh, PA	7.0	6.3	13.8	5.9	6.1	10.6	--	1.3	2.1	2.0
Shenandoah Park, VA	0.3	0.3	0.3	0.2	--	0.1	0.1	--	--	0.1
Charleston, WV	--	4.6	2.6	2.1	0.9	0.7	0.2	0.5	0.5	0.4
Grand Canyon, AZ	0.2	0.2	0.2	0.1	--	--	>0.1	>0.1	--	0.05
Gadsden, AL	--	2.4	1.8	2.5	1.2	1.2	0.8	0.5	0.6	0.6
Gary, IN	--	--	--	--	1.6	1.2	0.3	0.5	2.2	0.7
Indianapolis, IN	5.7	4.1	5.2	2.3	0.9	4.9	0.4	--	--	0.6
Baltimore, MD	3.8	2.3	2.8	2.1	2.8	1.3	0.4	0.5	0.6	0.5
Trenton, NJ	--	1.4	1.6	0.8	0.7	0.5	0.1	--	--	0.3
St. Louis, MO	2.3	--	3.3	--	0.8	0.6	0.2	0.3	0.3	0.3
Youngstown, OH	8.2	5.6	9.9	7.1	3.7	3.2	1.1	1.9	2.1	1.5
Chattanooga, TN	22.9	7.4	4.2	5.5	--	9.9	--	--	0.8	0.7
Spokane, WA	--	--	--	--	1.7	1.5	0.4	--	0.6	1.1

Table A-19 (Concluded)

Location	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Milwaukee, WI	--	4.7	4.0	2.5	1.8	3.6	0.6	--	1.1	0.3
Birmingham, AL	--	--	--	--	4.0	2.3	1.5	2.5	--	1.6
Jacksonville, FL	--	2.9	2.3	1.4	2.2	0.4	0.2	--	0.4	0.3
Honolulu, HI	0.5	0.6	0.6	0.2	0.2	0.1	0.2	0.4	0.03	0.02
Terre Haute, IN	3.7	--	4.0	2.8	--	1.1	--	0.3	0.6	0.6
Ashland, KY	--	9.3	10.9	6.7	9.0	8.5	2.9	--	4.7	4.7
Baton Rouge, LA	--	--	--	--	0.4	0.2	0.1	0.1	0.1	0.3
New Orleans, LA	1.8	1.6	1.5	1.1	0.9	0.4	0.3	0.3	0.2	0.2
Dearborn, MI	--	--	--	--	--	0.6	1.0	1.7	3.1	--
Duluth, MN	--	2.7	2.1	1.1	4.8	19.1	0.3	0.2	0.3	0.2
Buffalo, NY	--	--	--	--	--	1.5	0.6	0.8	0.5	--
Cleveland, OH	2.9	3.0	3.8	2.8	--	1.3	--	--	--	0.6
Bethlehem, PA	2.9	2.1	2.0	2.7	0.9	0.8	0.5	0.1	--	0.3
Erie, PA	--	--	--	--	1.5	2.4	0.7	0.6	0.4	0.2
Houston, TX	--	--	--	1.2	0.5	0.4	0.4	0.2	0.2	--
Newport News, RI	--	--	--	--	0.4	0.3	0.2	--	--	--
Norfolk, VA	3.5	4.9	3.9	1.8	1.2	0.6	0.4	0.2	0.2	0.5
Seattle, WA	1.8	2.0	1.6	1.5	0.5	0.5	0.3	--	0.4	0.7
St. Paul, MN	2.3	1.8	1.8	1.0	0.5	0.5	0.1	0.5	0.4	0.5
Arcadia National Park, ME	--	0.3	0.1	0.2	--	0.3	--	0.1	0.1	0.09
Hammond, IN	2.5	2.1	3.3	1.7	3.8	1.4	0.2	0.4	0.7	0.5

Table A-20

SEASONAL VARIATIONS OF BENZENE SOLUBLE ORGANIC SUBSTANCES ($\mu g/m^3$)

	1971				1972				
	1	2	3	4	1	2	3	4	Average
Birmingham, AL	3.1	6.7	-	4.8	3.6	7.5	4.0	5.2	4.99
Gadsden, AL	2.9	3.6	2.1	4.5	2.7	4.2	2.4	2.3	3.09
Montgomery, AL	3.4	4.2	2.4	3.4	3.3	2.9	2.2	2.6	3.05
Grand Canyon, AZ	1.2	0.9	-	-	-	-	-	-	1.05
Jacksonville, FL	4.3	3.0	2.1	2.2	2.3	5.4	4.4	6.0	3.71
Honolulu, HI	2.3	0.1	1.2	1.4	1.4	2.3	3.3	3.0	1.88
Chicago, IL	4.3	5.7	-	4.5	3.4	2.5	2.7	3.9	3.86
Gary, IN	4.7	2.7	-	5.7	2.7	4.1	3.0	2.5	3.63
Hammond, IN	3.8	4.7	6.0	7.0	2.1	9.4	6.3	5.0	5.54
Indianopolis, IN	2.6	3.1	3.2	3.7	2.9	4.9	3.0	-	3.34
Terre Haute, IN	4.1		3.6		2.5	5.7	4.0	6.3	4.37
Ashland, KY	6.8	7.4	4.0	8.3	7.8	7.2	7.9	9.2	7.33
Batan Rouge, LA	2.6	1.9	-	3.4	3.2	4.1	3.5	5.3	3.43
New Orleans, LA	4.0	3.5	3.1	3.5	3.7	4.9	5.5	4.2	4.05
Baltimore, MD	7.3	4.5	-	4.3	5.0	3.6	-	4.5	4.87
Dearborn, MI	-	3.2	3.1	-	3.6	7.3	4.6	4.5	4.38
Detroit, MI	2.6	3.0	2.4	3.9	3.2	3.3	3.4	3.0	3.10
Trenton, NJ	1.7	3.0	2.6	2.8	1.8	1.7	2.0	1.5	2.14
Duluth, MN	1.8	2.5	2.1	3.6	2.0	5.9	4.5	12.5	4.36

Table A-20 (Concluded)

	1971				1972				
	1	2	3	4	1	2	3	4	Average
St. Paul, MN	-	2.8	2.2	3.0	2.9	7.9	5.6	4.6	4.14
St. Louis, MO	5.5	3.1	2.0	-	2.9	3.7	2.3	2.6	3.16
Buffalo, NY	-	-	2.9	3.6	3.0	9.3	3.4	7.8	5.00
New York, NY	5.5	6.2	-	4.5	4.5	5.3	4.7	3.9	4.94
Cleveland, OH	3.6	3.6	-	-	3.1	6.5	-	4.6	4.28
Toledo, OH	2.1	2.4	-	3.1	1.8	-	2.9	2.7	2.50
Youngstown, OH	2.9	4.9	3.5	6.4	4.1	3.9	4.2	4.6	4.31
Bethlehem, PA	3.8	3.8	3.6	3.8	2.9	5.2	4.2	4.6	3.99
Erie, PA	2.6	2.5	-	4.2	1.3	6.8	5.8	-	3.87
Philadelphia, PA	6.0	4.0	3.8	7.4	4.7	3.8	4.3	3.3	4.66
Chattanooga, TN	4.8	5.1	-	-	4.1	11.0	3.7	-	5.74
Houston, TX	3.5	3.2	3.8	5.7	4.5	5.9	5.9	4.9	4.68
Newport News, VA	2.7	2.9	3.1	4.5	1.3	3.3	4.4	3.7	3.24
Norfolk, VA	4.9	4.0	3.5	4.2	2.5	3.8	3.8	3.2	3.74
Shennandoah, VA	-	0.7	0.9	-	1.0	0.9	0.8	0.6	0.81
Pittsburgh, PA	3.8	4.4	-	6.9	6.1	4.9	4.7	6.6	5.34
Seattle, WA	5.6	4.1	5.3	5.4	1.6	4.2	3.9	5.4	4.44
Spokane, WA	3.5	4.4	3.5	3.6	3.8	3.1	4.6	4.0	3.81
Charleston, WV	-	5.0	2.0	2.6	2.8	2.7	3.6	2.8	3.21
Milwaukee, WI	-	3.8	3.8	4.8	3.0	6.5	3.2	3.4	4.07

Table A-21

SUMMARIZATION OF AMBIENT BaP AND BSO DATA

Pollutant	Statistic	Cities With Coke Ovens	Cities Without Coke Ovens	Rural Areas
BaP (ng/m^3) 1975 data	Average	1.21	0.38	<0.10
	Sample size*	21	13	3
	Range	0.3-4.7	0.03-0.9	<0.10
BSO ($\mu g/m^3$) 1971-72 data	Average	4.21	3.75	0.95
	Sample size*	25	12	2
	Range	2.1-7.3	1.9-5.6	0.8-1.1

*Number of cities with annual average concentration data.

Table A-22

ANNUAL BaP AVERAGES FOR SELECTED CITIES
(ng/m^3)

Year	Cities With Coke Ovens	Cities Without Coke Ovens
1966	4.74 (15)*	2.76 (7)
1967	5.34 (15)	2.29 (8)
1968	3.75 (18)	2.64 (8)
1969	4.41 (23)	2.14 (11)
1970	3.02 (21)	1.41 (11)
1971	2.18 (11)	1.22 (8)
1972	2.14 (19)	0.64 (11)
1975	1.21 (21)	0.38 (13)
1976	0.93 (20)	0.41 (13)

*Number of cities included in average.

Source of 1966-1972 data: U.S. EPA (1974)

During 1976, samples taken by this surveillance system were also analyzed for BaP concentrations. The yearly average for these data, based on one day sampled per month, are given in Table A-23 by sampling location within the air basin. The highest average annual concentration was 56.35 ng/m^3 for Montessen and the next highest was 17.10 ng/m^3 for Johnstown. Both locations have coking operations. The lowest average concentration was 0.40 ng/m^3 for Hanover Green.

3. Charleston, South Carolina

BaP was analyzed for three collection sites in Charleston, South Carolina, which has no coke ovens. The data are summarized in Table A-24. The average concentration for the city was 0.69 ng/m^3.

4. Maryland Atmospheric Data

The Maryland State Division of Air Quality Control reports monthly composite BaP and BSO concentrations for many sites throughout the state. Data, primarily for 1976, are summarized in Table A-25. The average annual BaP concentrations ranged from 0.43 ng/m^3 for Harwood to 6 ng/m^3 for Catonsville.

5. CHESS and CHAMP Site Data

Atmospheric BaP and BSO data have been recorded for a number of CHESS and CHAMP sites throughout the country. These data are summarized in Table A-26. Average annual concentrations ranged from 0.63 ng/m^3 for Thousand Oaks, California to 4.2 ng/m^3 for one site in Birmingham, Alabama.

Table A-23

AMBIENT BaP CONCENTRATIONS FOR PENNSYLVANIA, 1976
(ng/m^3)

	Yearly Average*	Monthly Range
Allentown-Eastern Air Basin		
Allentown	0.71	0.09- 2.30
Tatamy	0.80	0.11- 2.74
Bethlehem	1.11	0.22- 4.15
Easton	1.86	0.39- 9.28
Bethlehem East	1.46	0.24- 6.34
Emmaus	1.29	0.10- 7.62
Allen Twp.	0.55	0.06- 2.24
Northampton	0.76	0.10- 3.43
(Basin average)	1.08	--
Beaver Valley Air Basin		
New Castle	3.06	0.13-11.36
Bessemer	1.41	0.46- 2.21
Koppel	9.43	0.30-78.08
Beaver Falls	5.03	0.42-12.65
Vanport	2.27	0.16- 5.44
Rochester	4.19	0.35-13.96
Ambridge	6.18	0.75-31.96
Baden	9.00	0.40-43.48
Midland	3.13	0.31- 8.60
Brighton	2.42	0.34- 9.74
(Basin average)	4.73	--
Erie Air Basin		
Millcreek Twp.	0.45	0.12- 0.87
Erie Central	2.04	0.26- 7.13
Erie South	1.16	0.21- 3.77
Erie East	1.62	0.23- 6.33

*Based on one sample per month for 12 months.

Source: Dubin (1977)

Table A-23 (Continued)

	Yearly Average	Monthly Range
Harborcreek Twp.	0.60	0.13- 3.40
(Basin average)	1.20	--
Harrisburg Air Basin		
Middletown	0.83	0.12- 2.10
Swatara Twp.	0.65	0.18- 1.42
Steelton	1.03	0.32- 2.98
Lemoyne	0.92	0.28- 2.38
Susquehanna Twp.	0.90	0.13- 2.55
Harrisburg	0.81	0.15- 2.00
Summerdale	0.61	0.14- 1.60
(Basin average)	0.82	--
Johnstown Air Basin		
Westmont	1.00	0.15- 5.05
Johnstown North	17.14	0.31-75.54
Johnstown Central	4.41	0.24-10.69
E. Conemaugh	16.30	1.21-50.74
Johnstown South	4.78	0.32-23.01
Hornerstown	3.17	0.13- 8.16
(Basin average)	7.51	--
Lancaster Air Basin		
Lancaster Twp.	0.54	0.15- 1.77
Lancaster General	1.01	0.21- 2.74
Lancaster East	10.82	0.19-122.7
Lancaster North	0.72	0.27- 2.53
Lancaster West	0.91	0.25- 3.10
Neffsville	0.68	0.11- 1.81
Manheim Twp.	0.73	0.12- 2.75
(Basin average)	2.28	--

Table A-23 (Continued)

	Yearly Average	Monthly Range
Monessen Valley Air Basin		
New Eagle	2.78	0.31- 7.51
Monessen	56.38	1.05-206.3
Lover	2.61	0.61- 9.66
Elco	0.96	0.12- 3.94
Brownsville	9.05	0.59-57.00
Charleroi	2.47	0.13- 6.99
(Basin average)	12.69	--
Reading Air Basin		
Leesport	0.56	0.07- 1.60
Reading South	0.94	0.18- 3.20
Shillington	1.02	0.10- 4.09
Sinking Spring	0.73	0.05- 2.26
Reading Central	0.83	0.17- 2.67
Temple	0.90	0.15- 3.73
Laureldale	0.94	0.20- 3.32
(Basin average)	0.85	--
Scranton-Wilkes-Barre Air Basin		
Hanover Green	0.40	0.09- 1.04
Dickson City	1.35	0.18- 3.32
Jessup	2.00	0.15-13.70
Pittston	1.49	0.14- 3.60
Swoyersville	1.67	0.42- 3.67
Nanticoke	0.94	0.11- 3.26
Wilkes-Barre	1.82	.19- 9.00
Scranton	2.06	0.28- 4.25
Dupont	1.30	0.27- 2.41
Avoca	0.44	0.11- 0.97
West Nanticoke	0.79	0.14- 2.05
(Basin average)	1.32	--

Table A-23 (Continued)

	Yearly Average	Monthly Range
Southeast Pennsylvania Air Basin		
Pottstown	1.06	0.36- 3.09
Bristol	0.91	0.20- 3.03
Willow Grove	1.05	0.32- 3.93
Dowingtown	0.69	0.19- 2.48
Doylestown	0.76	0.12- 3.21
Media	1.00	0.24- 3.11
Chester	0.56	0.14- 1.78
Perkasie	0.73	0.16- 2.53
Quakertown	0.48	0.08- 1.84
West Chester	0.81	0.11- 2.62
Lansdale	1.36	0.18- 4.57
Conshohocken	2.06	0.40- 3.24
Phoenixville	0.80	0.12- 2.47
Morrisville	0.79	0.07- 2.55
Coatsville	0.64	0.07- 1.42
(Basin average)	0.92	--
York Air Basin		
York East	0.98	0.17- 2.59
York Central	0.96	0.17- 3.13
West Manchester Twp.	0.78	0.12- 3.38
Manchester Twp.	0.41	0.07- 1.12
West York	0.77	0.19- 2.16
Springettsbury	1.15	0.11- 7.49
(Basin average)	0.84	--
Altoona Area		
Altoona Central	3.49	0.29-17.10
Altoona East	5.80	0.31-22.20
(Area average)	4.64	--

Table A-23 (Concluded)

	Yearly Average	Monthly Range
Farrell-Sharon Area		
Farrell	2.46	0.44- 8.54
Sharon	2.45	0.24- 9.22
(Area average)	2.46	--
Williamsport Area		
Williamsport Central	1.02	0.23- 4.14
Williamsport East	1.28	0.15- 8.56
(Area average)	1.15	--

Table A-24

DISTRIBUTION OF BaP CONCENTRATIONS IN AMBIENT AIR AT CHARLESTON, SOUTH CAROLINA*
(ng/m^3)

Site Number	Location	Sample Size	Average	Range
1	Radio Station WTMA	22	0.5711	0.0028-1.2409
2	Queen St. Fire Station	22	0.7441	0.1693-1.6787
3	Mt. Pleasant, Post Office	22	0.7448	0.1995-1.9767
	Total	66	0.6866	0.0028-1.9767

*There are no coke ovens in Charleston.

Source: Spangler and de Nevers (1975).

Table A-25

AMBIENT ATMOSPHERIC BaP AND BSO CONCENTRATIONS FOR MARYLAND LOCATIONS

Location	BaP (ng/m^3) Sample Size*	Average	Range	BSO ($\mu g/m^3$) Sample Size*	Average	Range
Cumberland	12	4.48	0.40-20.22	12	8.44	6.03-18.14
Hagerstown	12	1.40	0.20-3.87	12	4.74	3.34-7.40
Adamstown	7	0.83	0.31-2.12	--	--	--
Frederick	12	1.29	0.18-3.55	12	4.80	3.48-6.77
Myersville	7	0.17	0.05-0.55	--	--	--
Buckeystown	8	0.80	0.16-2.52	--	--	--
Glen Burnie	11	1.03	0.15-2.82	12	4.84	2.67-7.76
Harmons	12	0.54	0.09-2.10	--	--	--
Harwood	12	0.43	0.04-1.13	12	2.93	1.52-4.51
Linthicum	12	0.96	0.15-2.18	12	3.99	2.21-7.49
Odenton	12	0.71	0.08-1.75	12	3.69	1.93-5.74
Riviera Beach	12	0.80	0.10-2.79	12	4.25	2.50-6.14
Annapolis	11	0.75	0.10-1.83	12	3.76	2.29-4.93
Baltimore						
Lexington and Gay	12	1.95	0.41-4.46	12	6.27	4.34-8.64
Sun Avenue	12	2.03	0.50-4.43	12	6.88	3.35-9.50
1900 Argonne	12	1.21	0.27-3.51	12	4.21	2.51-7.24
5700 Reisterstown	12	1.37	0.42-4.76	12	5.26	3.25-8.11
5700 Eastern	12	1.92	0.38-5.36	12	6.38	4.25-10.06
Fonthill St.	12	1.66	0.37-4.80	12	5.24	3.01-8.68
Cockeysville Ind. Pk.	11	0.80	0.09-4.83	--	--	--
Cockeysville Police Station	8	0.50	0.12-1.76	8	4.11	2.15-9.99
Police Barracks	12	0.78	0.10-2.06	12	4.79	2.35-7.40
3001 Eastern Blvd.	11	1.29	0.18-3.97	11	4.89	3.27-6.60
Catonsville	12	5.98	0.09-2.08	12	4.02	2.53-6.22
Dundalk (8801 Wise Ave.)	10	1.10	0.56-2.42	--	--	--
Edgemere	10	1.85	0.07-2.60	--	--	--
Essex	12	1.37	0.19-4.36	12	5.35	3.00-7.98
Fort Howard	10	2.39	0.38-5.41	10	4.79	2.64-8.66
Towson	10	0.75	0.09-2.95	3	5.48	4.16-6.41
Middle River	2	1.43	1.14-1.71	2	6.52	6.25-6.79
Dundalk (Kavanaugh Rd.)	11	1.61	0.53-4.60	--	--	--
Dundalk (Reg. Voc. Training)	10	3.30	0.31-10.35	--	--	--
Westminster	12	0.49	0.09-1.49	12	3.07	1.95-4.78

Table A-25 (Concluded)

Location	Sample Size*	BaP (ng/m^3) Average	BaP (ng/m^3) Range	Sample Size*	BSO ($\mu g/m^3$) Average	BSO ($\mu g/m^3$) Range
Gaithersburg	10	0.62	0.09-2.13	10	3.60	2.00-5.17
Silver Spring (1901 Randolph)	10	1.14	0.09-5.80	11	4.83	2.51-11.69
Kensington	11	0.59	0.09-2.07	11	4.26	3.05-7.56
Poolesville	11	0.46	0.06-1.40	12	3.36	1.89-5.18
Silver Spring (Rock Creek Forest)	4	1.83	0.58-3.93	--	--	--
Rockville	12	0.96	0.07-4.57	12	4.51	2.56-8.89
Bethesda	4	1.25	0.71-1.68	--	--	--
Accokeek	2	1.06	0.73-1.38	--	--	--
Cheverly	11	0.65	0.17-1.50	11	4.57	3.45-6.24
Largo	1	1.30	--	--	--	--
Laurel	10	0.52	0.09-1.37	10	3.56	1.90-5.31
Orme	10	0.49	0.08-1.90	10	3.56	2.51-5.33
Oxon Hill	8	0.70	0.07-1.50	8	4.03	3.08-5.80
Laplata	10	0.34	0.17-1.68	10	3.27	2.38-4.95
Elkton	12	1.02	0.18-2.73	12	4.60	3.55-6.76
Cambridge	11	0.62	0.18-1.58	11	4.05	2.55-5.80
Salisbury	9	0.58	0.10-1.59	10	4.46	3.03-5.50

*Number of months of data used in calculating the average and range.

Table A-26

ATMOSPHERIC BaP AND BSO CONCENTRATIONS FOR CHESS AND CHAMP SITES (1975 DATA)

Location*	Sample Size**	BaP (ng/m^3) Mean	BaP (ng/m^3) Range	BSO ($\mu g/m^3$) Mean	BSO ($\mu g/m^3$) Range
Charlotte, NC (1)	6	1.44	0.3-2.7	1.79	1.1-2.3
Charlotte, NC (2)	6	2.36	0.5-4.4	2.91	2.2-3.8
Riverhead, NY	12	0.66	0.0-3.6	1.29	0.6-2.0
Queens, NY	12	1.07	0.1-3.1	1.99	0.9-2.8
Brooklyn, NY	12	1.57	0.3-4.0	3.70	1.1-7.6
Bronx, NY	12	2.11	0.2-4.3	3.24	2.0-3.6
Ogden, Ut	12	2.05	0.0-7.2	2.41	0.7-8.8
Salt Lake City, Ut	12	2.37	0.2-5.0	3.26	1.6-7.7
Kearns, Ut	12	1.20	0.1-3.6	1.43	0.7-3.2
Magna, Ut	12	1.09	0.1-2.9	1.48	0.5-3.4
Vista, CA	12	1.03	0.1-4.9	2.07	0.8-6.7
Santa Monica, CA	6	1.46	0.2-3.5	3.91	1.1-6.1
Thousand Oaks, CA	12	0.63	0.1-1.4	2.31	1.1-4.8
Garden Grove, CA	12	2.42	0.3-7.5	3.86	0.8-11.9
Glendora, CA	12	0.91	0.1-2.2	4.13	0.5-6.5
West Covina, CA	12	1.98	0.2-5.0	5.85	2.6-9.5
Anaheim, CA	12	2.36	0.4-7.1	4.77	1.6-11.2

*Data for Birmingham and Chattanooga are given with the city coke oven data in Tables A-8 and A-15, respectively.

**Number of months for which data are available; sample size for individual months generally ranged from 20 to 31 days.

Appendix B

STATISTICAL EVALUATION OF BaP ATMOSPHERIC CONCENTRATION DATA RECORDED IN THE VICINITY OF COKE PLANTS

Appendix B

STATISTICAL EVALUATION OF BaP ATMOSPHERIC CONCENTRATION DATA RECORDED IN THE VICINITY OF COKE PLANTS

A. General

This appendix presents a statistical evaluation of the BaP atmospheric concentration data recorded in the vicinity of coke plants. Factors addressed here include the following:

- What is the statistical distribution for atmospheric BaP concentrations over time at a given location?
- What errors are introduced by using estimated annual atmospheric concentrations, based on a small sample size?
- Can the average BaP concentrations around a coke plant be described as a mathematical function relating average concentration to distance from the plant?

B. Statistical Distribution of 24-Hour BaP Atmospheric Concentrations

Because of changes in meteorological conditions and other factors, the atmospheric BaP concentration at a specified location in the vicinity of a coke plant will vary from day to day. The day-to-day variations in the recorded 24-hour concentrations form a statistical distribution. The long-term concentration for a specified location is generally characterized by some central parameter for the distribution like the arithmetic or geometric mean or the median. Obviously, the atmospheric concentration data have been found to follow a distribution having relatively many small values, with a few observations ranging to fairly high values. These are called skewed distributions, as contrasted with symmetrical distributions. They are sometimes found to follow what is known as two- or three-parameter lognormal distributions.

Figure B-1 illustrates the cumulative statistical distribution for BaP atmospheric concentrations from some sampling locations. Because the plotted points approximate a straight line, the statistical distributions might be approximated by a lognormal distribution. The central measure that best characterizes this type of distribution is the geometric rather than the arithmetic average. The geometric average for these types of distributions is smaller than the arithmetic average.

The properties of the lognormal distribution should be used when describing the probability that a particular BaP atmospheric concentration

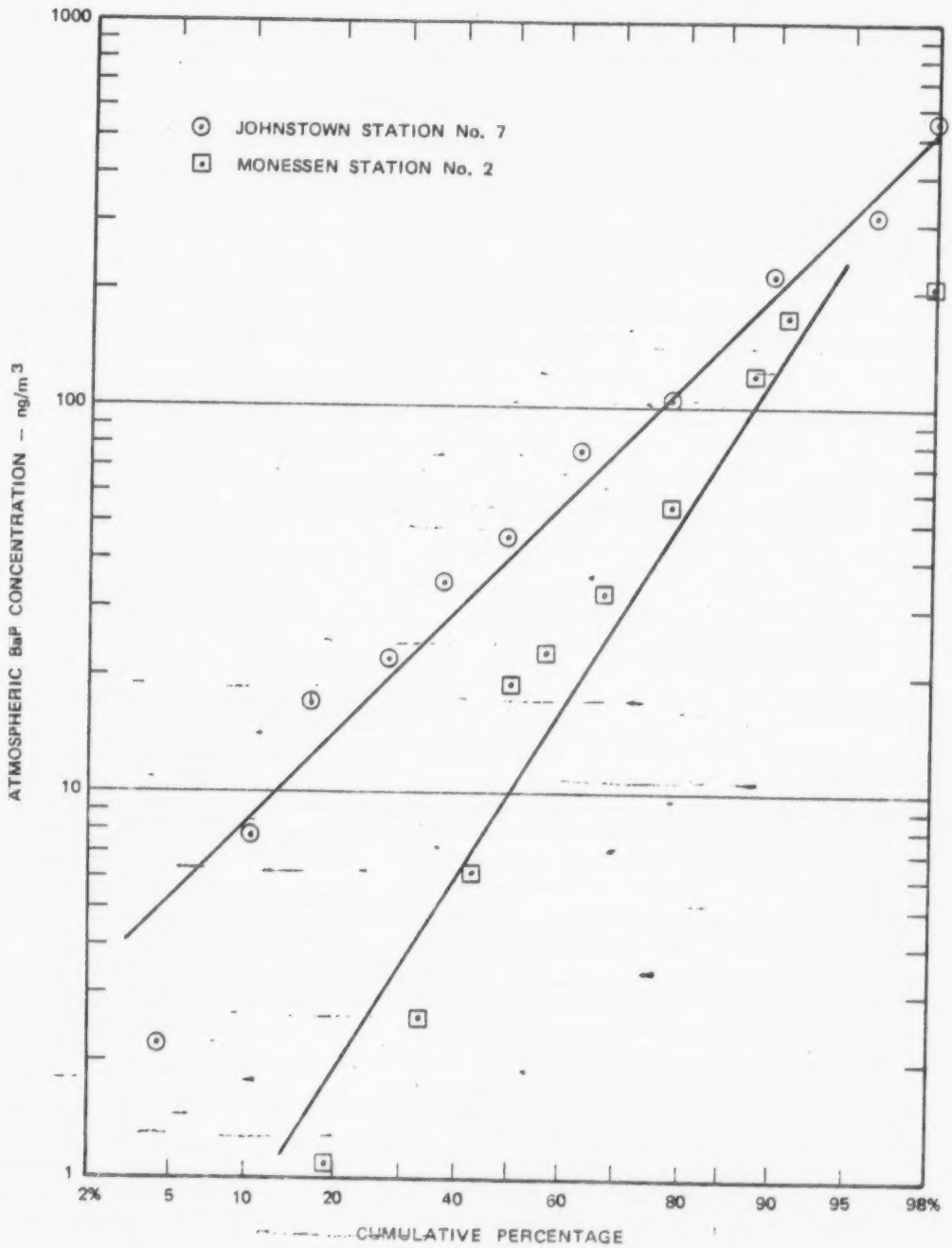


FIGURE B-1. STATISTICAL DISTRIBUTION FOR ATMOSPHERIC BaP CONCENTRATIONS

will occur at a specified location. However, the arithmetic average should be used when estimating expected population exposures. That is, the arithmetic average concentration when used with daily human ventilation rates gives the expected daily inhalation exposure. This expected daily inhalation exposure multiplied by 365 gives the estimated total annual exposure. The point here is that the arithmetic average should be used in estimating expected population exposures, and the properties of the lognormal distribution should be used in estimating the probability of a specified exposure.

Table B-1 summarizes the arithmetic and geometric average and standard deviations for samples recorded at a number of stations. It is of interest and potentially useful that the coefficient of variation (standard deviation divided by the average) has a value near 1 (i.e., the standard deviation generally equals the average).

C. Precision of Estimates Based Upon Small Sample Sizes

Most of the ambient sampling data available for this study are based on 24-hour samples collected during limited sampling days. The ambient concentrations recorded for these dates, for a given location, are averaged and used as an estimate of the annual average concentration for that location. It is, therefore, desirable to know how well an estimated average annual concentration approximates the actual annual concentration.

From a statistical viewpoint, it is first necessary to know if the sampling dates or period of dates were selected at random. In fact, sampling was probably conducted when people get around to it or are forced to do it and not because of any particular meteorological or seasonal reasons. If this is the case, it might be assumed that the sampling period was selected in a quasirandom manner.

The next point has to do with weighting the samples for individual dates by the fraction of time the meteorological condition on that date occurs during the year. This generally is not done because in some cases the meteorological conditions at the time of sampling are not reported or because representative sampling is not available for a range of probable meteorological conditions. If it can be assumed that the sampling period is taken at random and that no weighting of the samples is to be made, the estimation reduces to a simple statistical random sampling problem. In this case, the average of the available data becomes an unbiased estimate of the average concentration over the year. However, the number of dates for which data are available greatly affects the precision of the estimated annual average.

The precision of an estimated value is measured by its standard deviation. For a simple random sampling problem, the standard deviation for an estimated annual average is given by:

$$P = Sf \quad ,$$

Table B-1

STATISTICAL SUMMARY FOR SAMPLING DATA TAKEN FROM A NUMBER OF LOCATIONS

Sampling Location	Sample Size	Arithmetic			Geometric	
		Average	Standard Deviation	Coefficient of Variation*	Average	Standard Deviation
Monessen, 2	29	40.8	58.9	1.4	10.0	7.6
Monessen, 6	28	2.7	2.8	1.0	1.0	2.8
Monessen, 7	31	22.8	26.3	1.2	10.1	4.6
Johnstown, 1	30	3.6	3.3	0.9	2.6	2.3
Johnstown, 2	32	13.8	19.8	1.4	8.6	2.5
Johnstown, 3	33	7.7	7.5	1.0	5.7	2.2
Johnstown, 4	32	23.4	43.2	1.8	13.2	2.5
Johnstown, 5	28	6.0	3.0	0.5	5.2	1.8
Johnstown, 6	31	6.8	5.0	0.7	5.6	1.9
Johnstown, 7	34	85.3	112.0	1.3	44.5	3.6
Johnstown, 8	31	19.7	28.0	1.4	8.3	3.9
Utah, 1	9	2.1	1.3	0.6	1.7	2.2
Utah, 2	6	3.8	0.9	0.2	3.7	1.3
Utah, 3	9	3.2	2.0	0.6	2.6	1.9
Utah, 4	11	2.4	1.6	0.7	2.0	2.0
Utah, 5	11	3.1	1.9	0.6	2.5	2.2
Utah, 6	11	1.6	1.0	0.6	1.4	1.9
Utah, 7	3	2.1	1.3	0.6	1.8	2.0
Utah, 8	11	1.5	1.0	0.7	1.2	2.2
Utah, 9	11	0.1	0.1	1.0	0.1	2.9
Utah, 10	9	0.8	0.8	1.0	0.5	3.4
Gadsden, 1	5	0.6	0.6	1.0	0.3	1.8
Gadsden, 2	5	1.9	1.4	0.7	1.6	1.9
Duluth, 1	18	1.5	2.0	1.3	0.3	13.2
Duluth, 2	20	0.2	0.3	1.5	0.1	17.7

*The standard deviation divided by the average.

where

P = the standard deviation of the estimated annual average.

S = the calculated standard deviation for the sampling data.

$f = \sqrt{\frac{365 - n}{365\ n}}$.

n = the sample size.

The factor labeled as f is called the finite sample correction factor, some values of which follow:

Sample Size	Finite Sample Correction Factor
1	0.999
5	0.444
10	0.319
20	0.217
30	0.175
50	0.131
100	0.085
200	0.048
365	0.000

Note that the finite sample correction factor reduces in size rapidly with additional sampling when the sample size is small. Depending on the standard deviation for the sampling data, one might reasonably want sample sizes in excess of 30. Estimates based on sample sizes of less than 10 might be suspected of being quite imprecise.

D. Evaluation of Ambient Concentration Data as a Function of Distance from Coke Plant Locations

Available ambient data that have been recorded in the vicinity of coke plants (Appendix A) are evaluated to determine if it is mathematically possible to represent the relationship of BaP concentration as a function of distance from the coke plant. To investigate the feasibility of an approach using recorded ambient concentrations, the average atmospheric concentrations have been plotted as a function of distance from the coke plants (Figures B-2 through B-14). As might be expected, the atmospheric concentrations decrease with increasing distance from the coke plants, thus indicating that the coke plants are a possible source of BaP. The moderate amount of scatter in these relationships is probably due to such factors as the location of the sampling site with respect to the coke plant, local meteorological conditions, and local geography. In addition, because many of the areas have several coke plants, it is difficult to characterize the contribution to the environment for an individual plant.

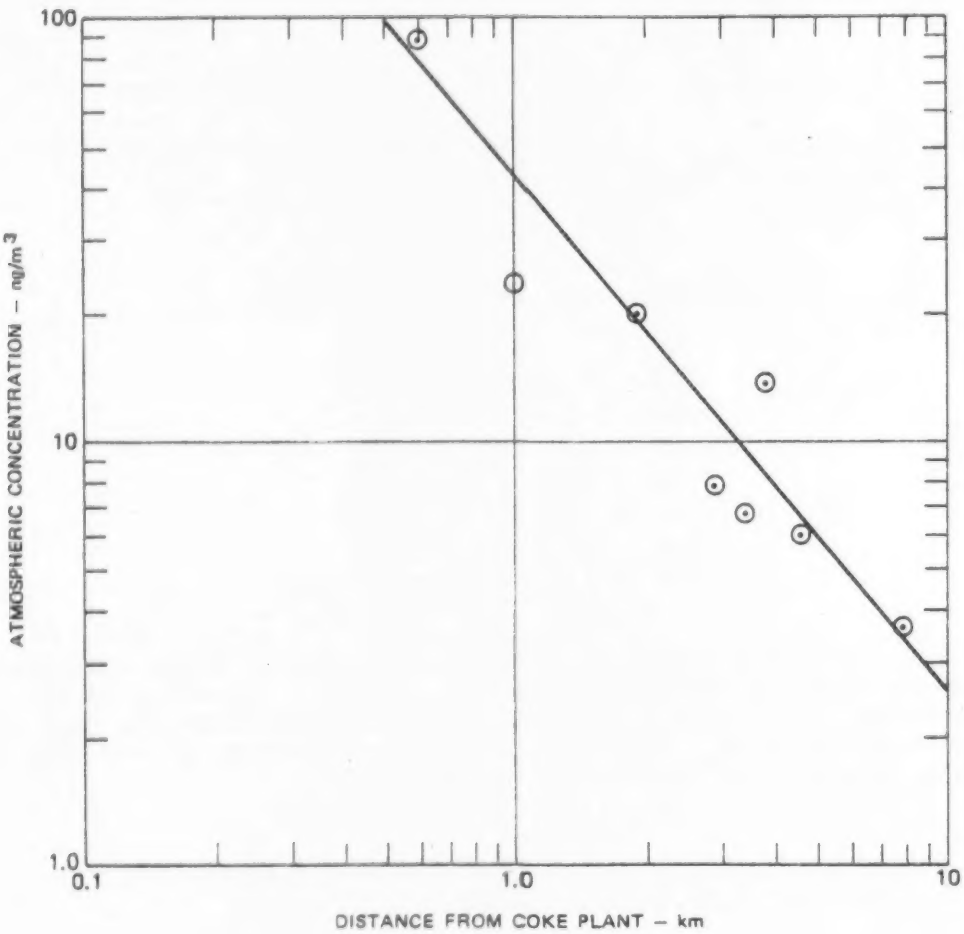


FIGURE B-2. ATMOSPHERIC CONCENTRATIONS OF BaP FOR JOHNSTOWN, PENNSYLVANIA

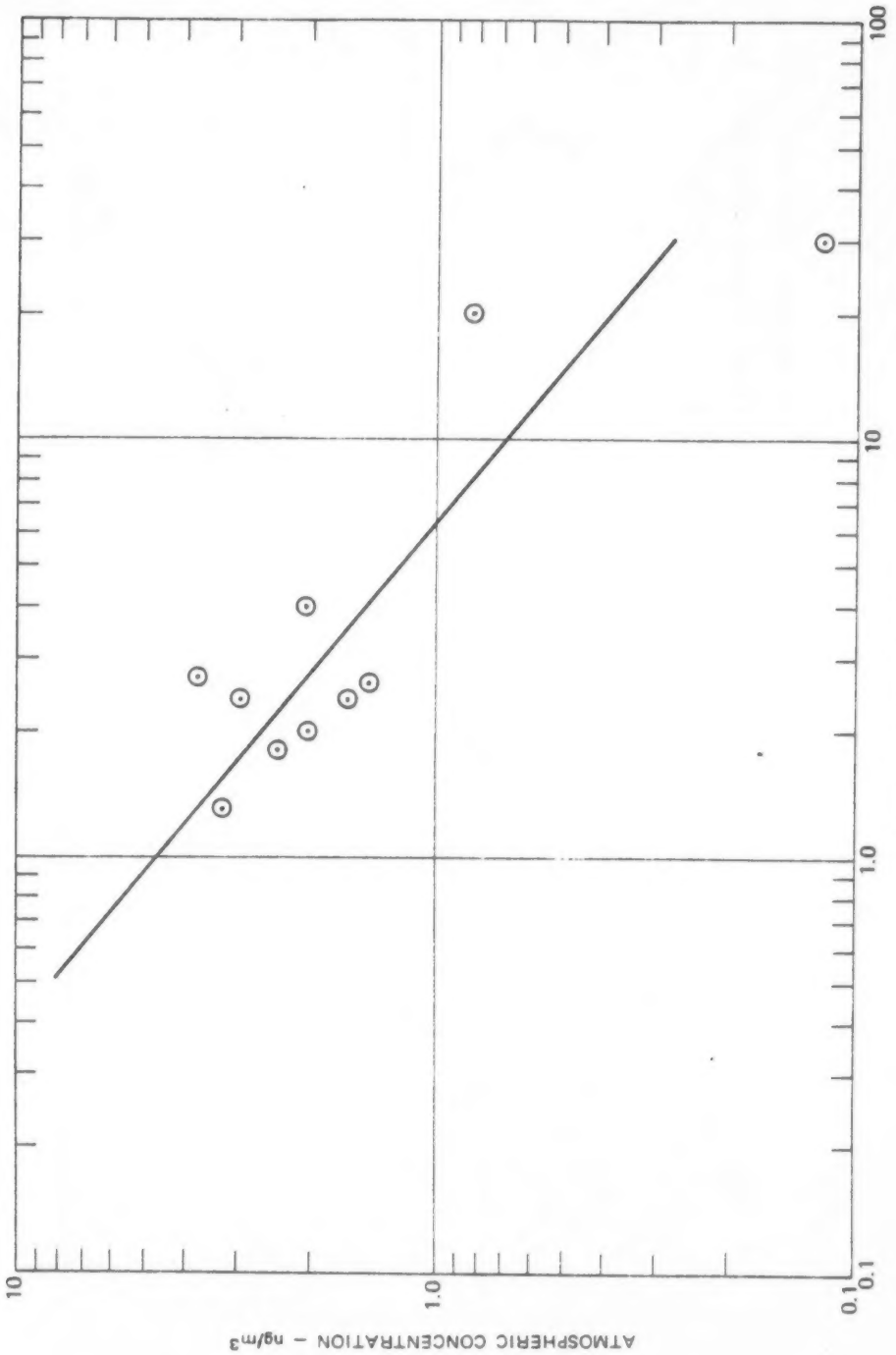


FIGURE B-3. ATMOSPHERIC CONCENTRATIONS OF BaP FOR GENEVA, UTAH

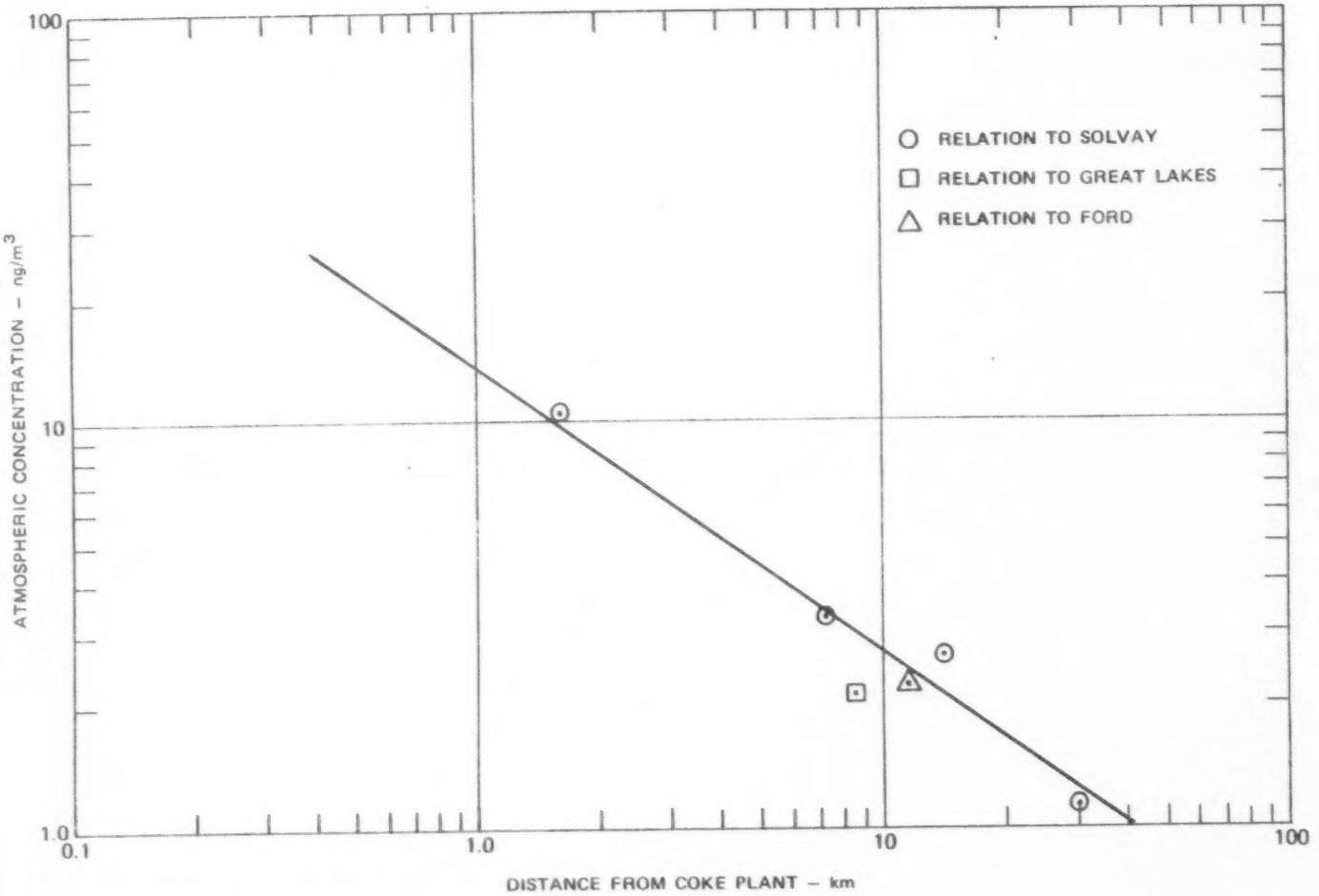


FIGURE B-4. ATMOSPHERIC CONCENTRATIONS OF BaP FOR WAYNE COUNTY, MICHIGAN

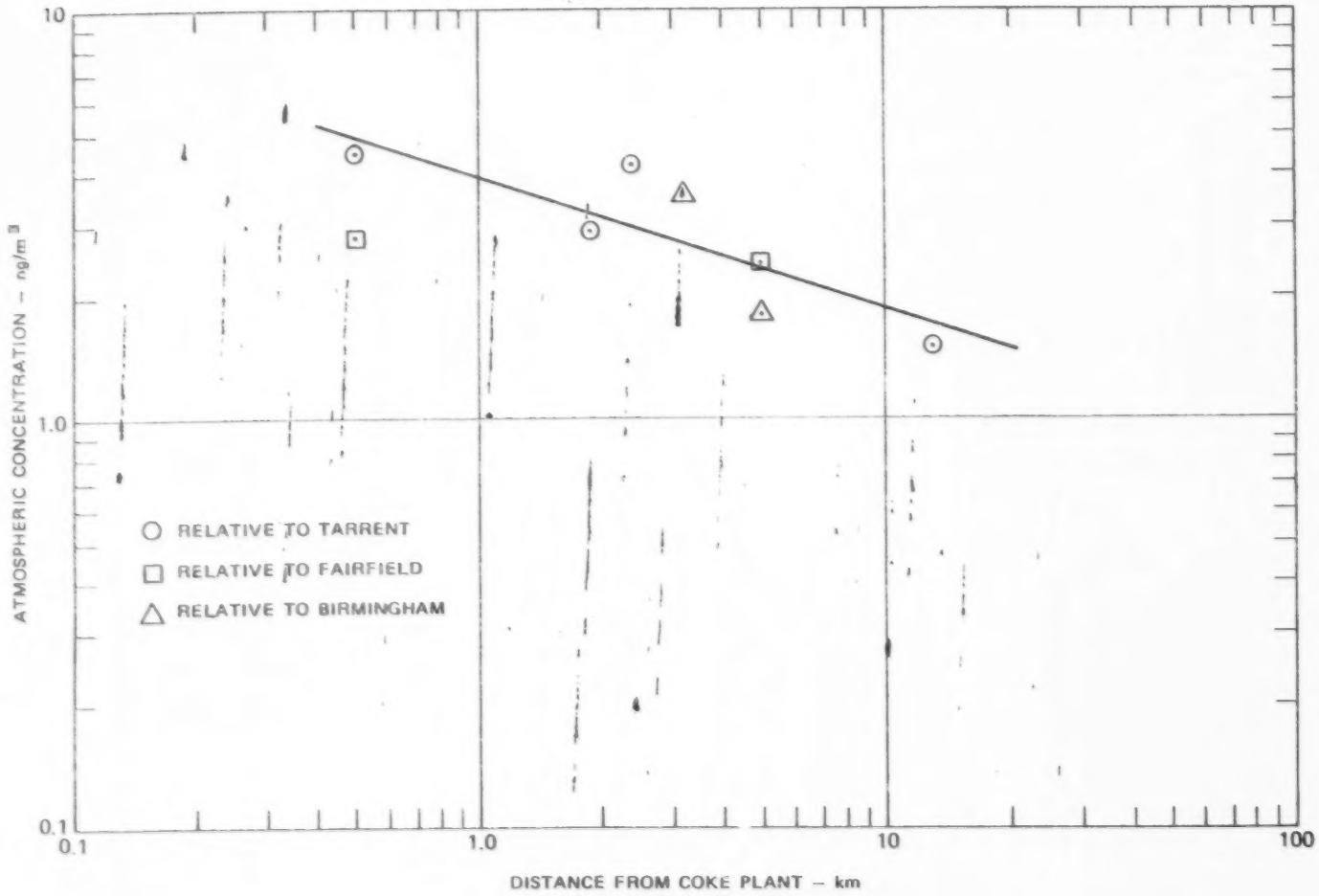


FIGURE B-7. ATMOSPHERIC CONCENTRATIONS OF BaP FOR BIRMINGHAM, ALABAMA

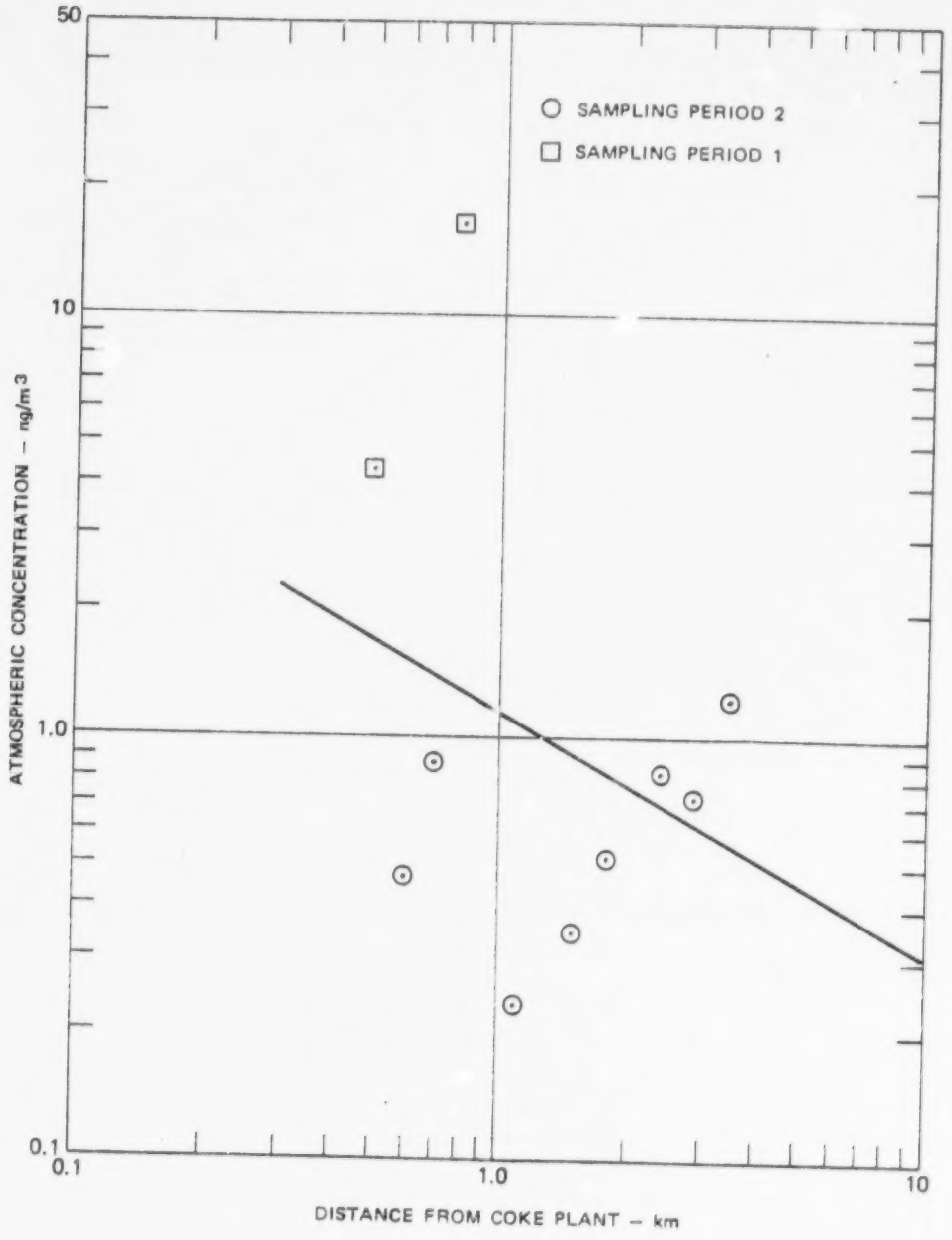


FIGURE B-8. ATMOSPHERIC CONCENTRATIONS OF BaP FOR GRANITE CITY, ILLINOIS

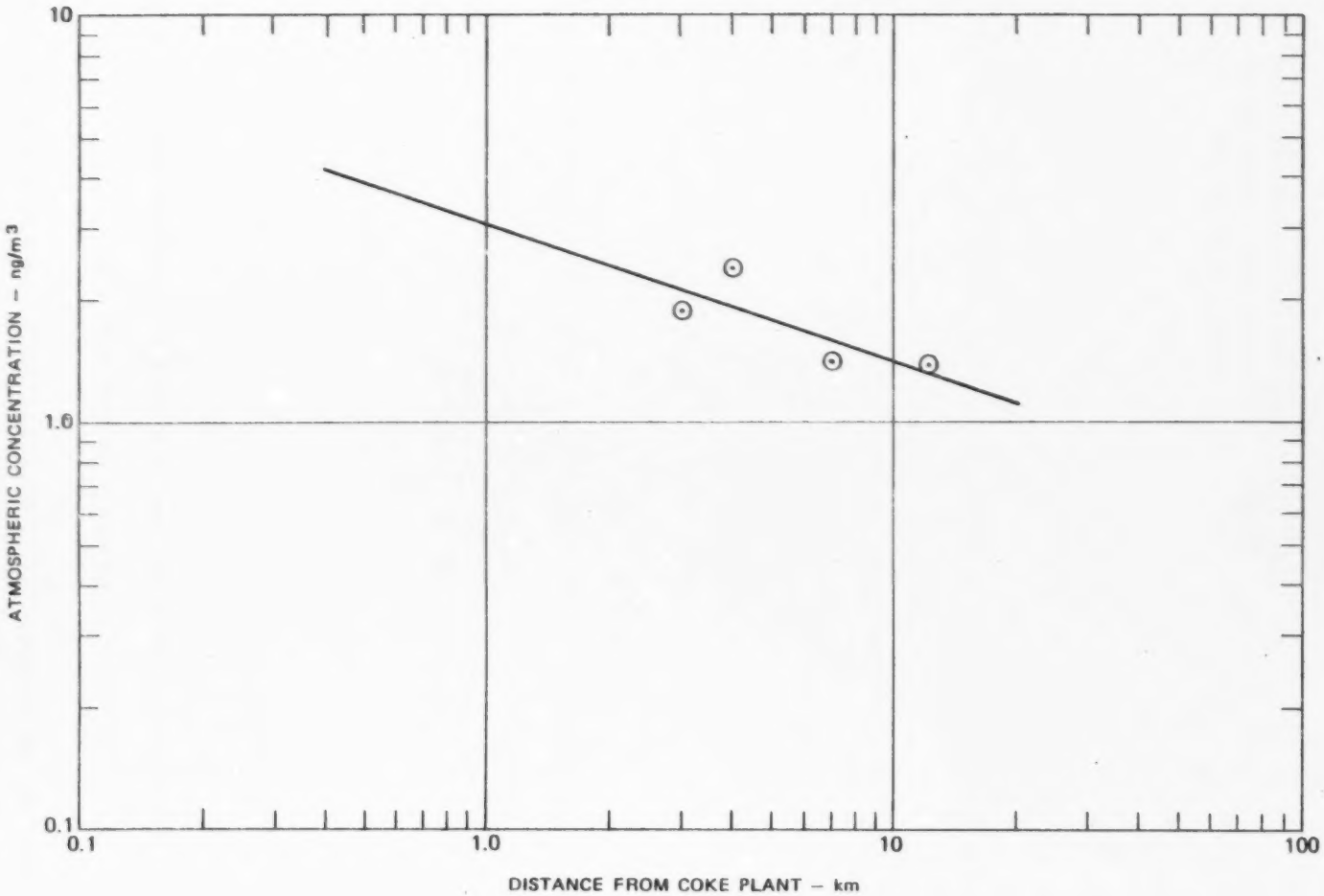


FIGURE B-9. ATMOSPHERIC CONCENTRATIONS OF BaP FOR SPARROWS POINT, MARYLAND

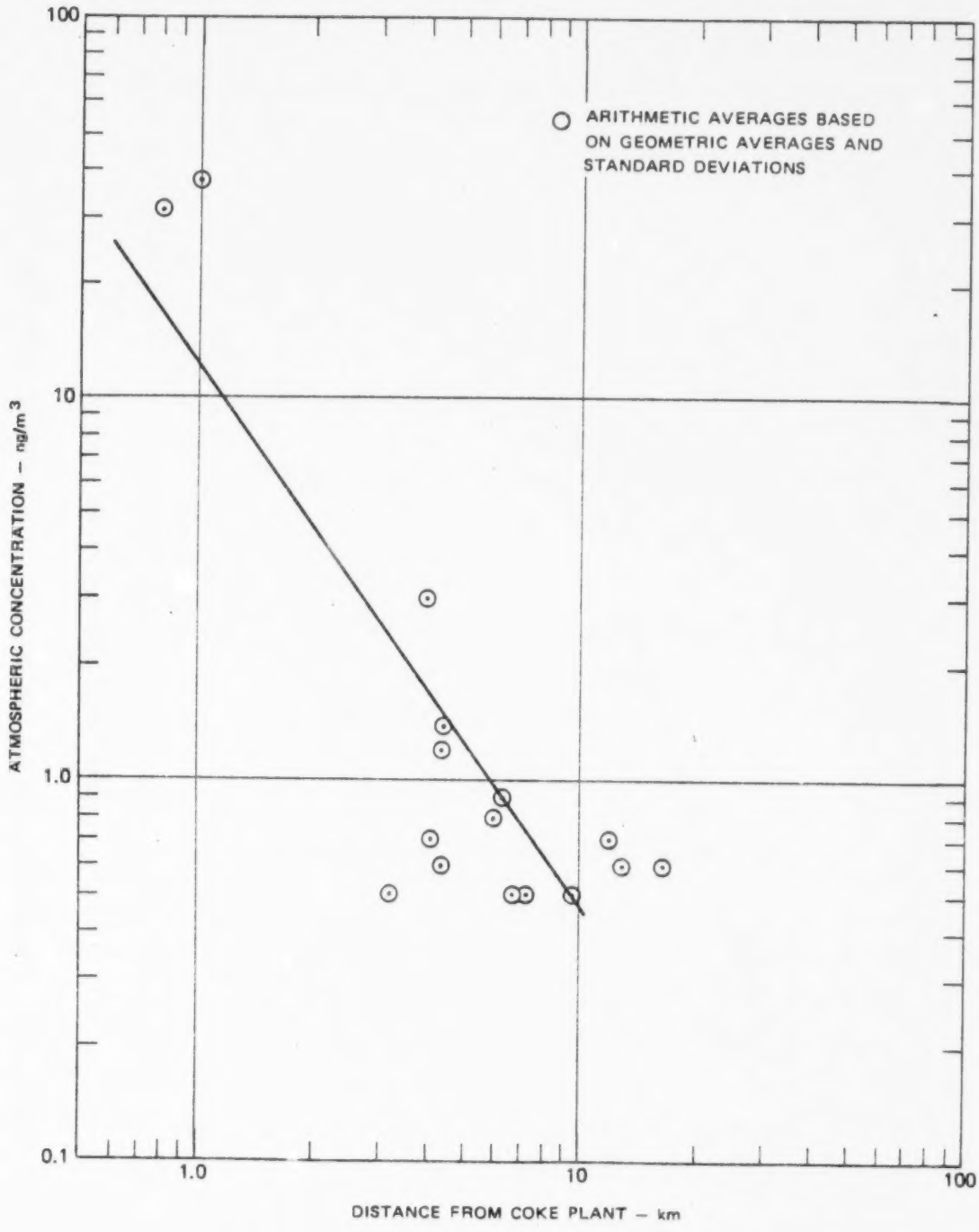


FIGURE 8-10. ATMOSPHERIC CONCENTRATIONS OF BaP FOR CLEVELAND, OHIO

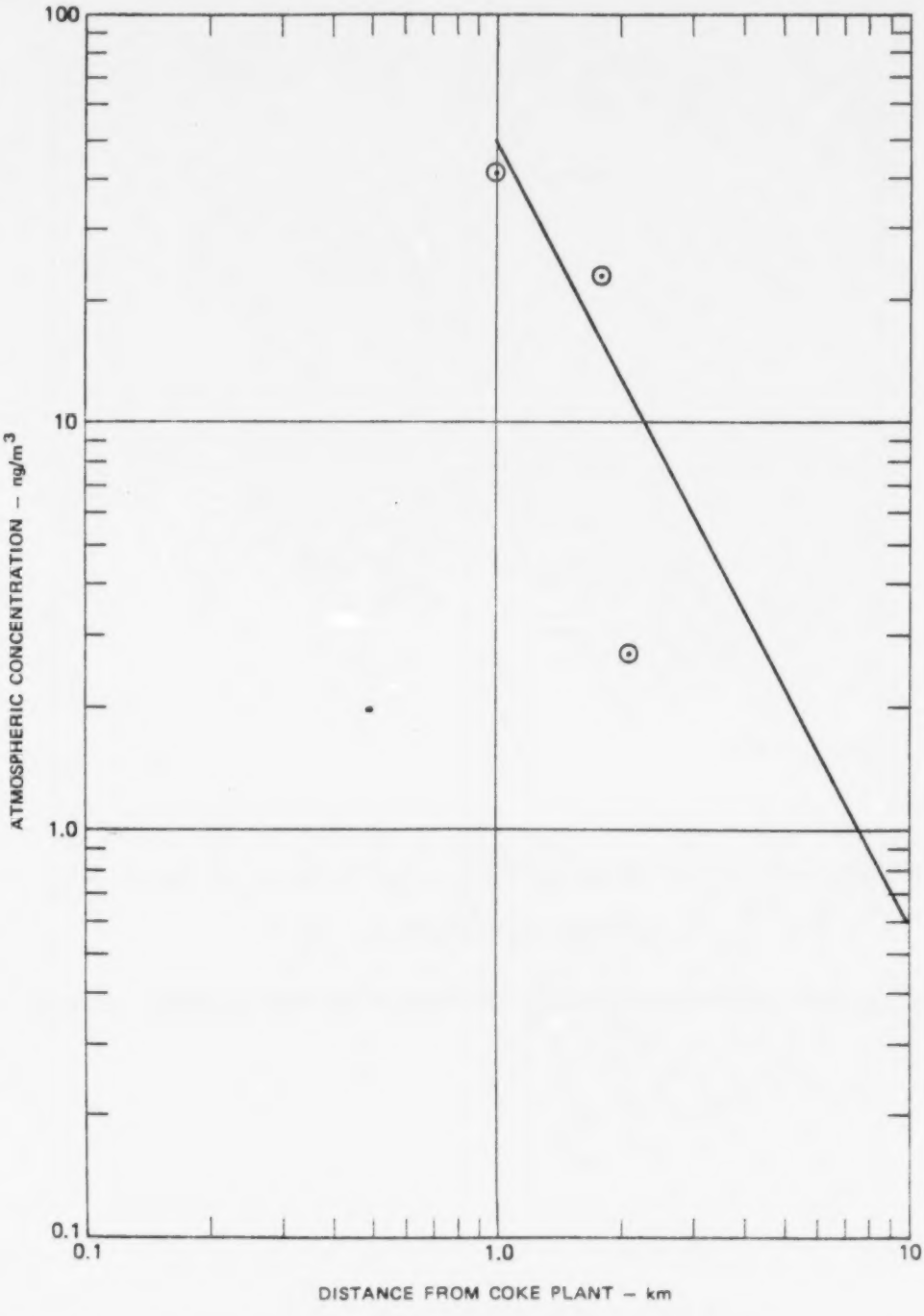


FIGURE B-11. ATMOSPHERIC CONCENTRATIONS OF BaP FOR MONESSEN, PENNSYLVANIA

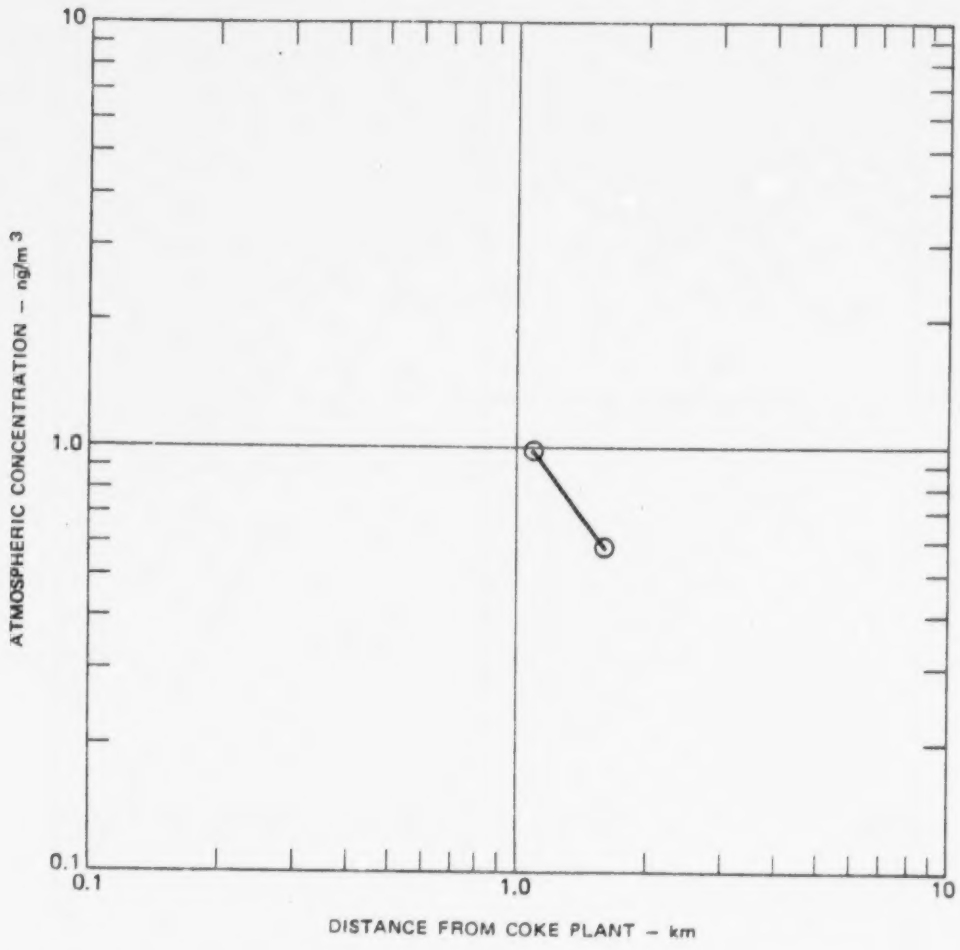


FIGURE B-12. ATMOSPHERIC CONCENTRATIONS OF BaP FOR GADSDEN, ALABAMA

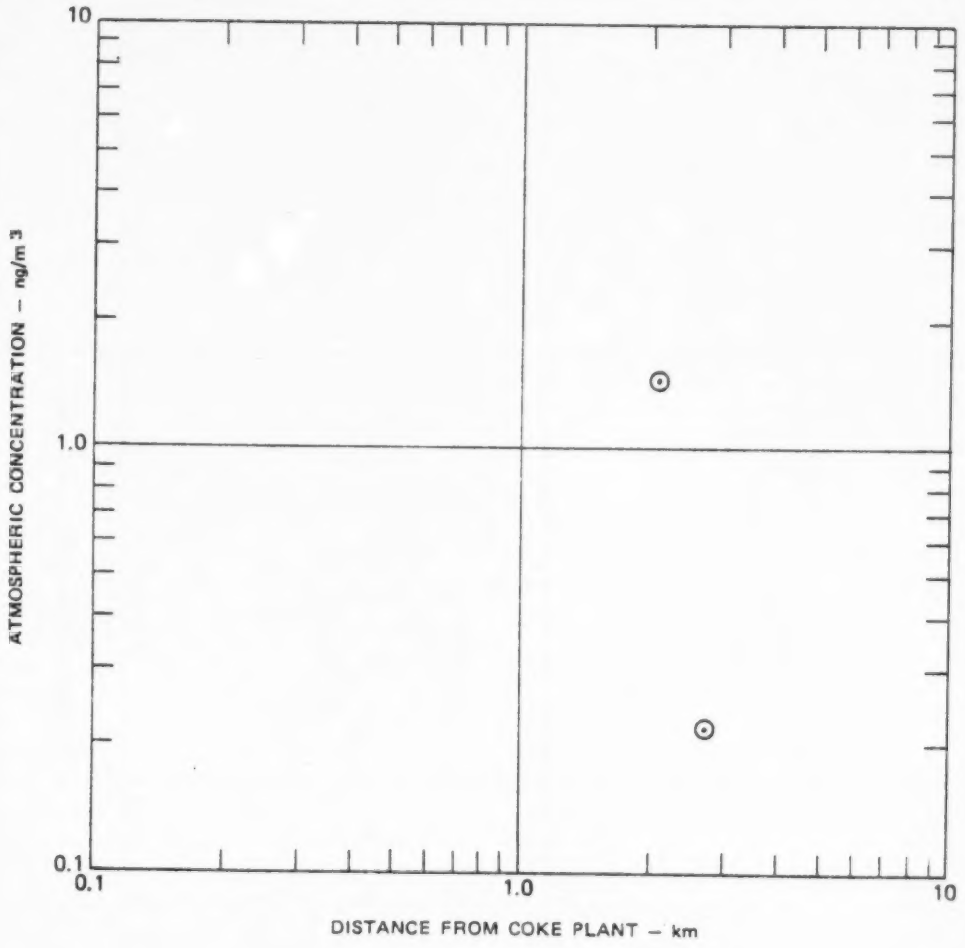


FIGURE B-13. ATMOSPHERIC CONCENTRATIONS OF BaP FOR DULUTH, MINNESOTA

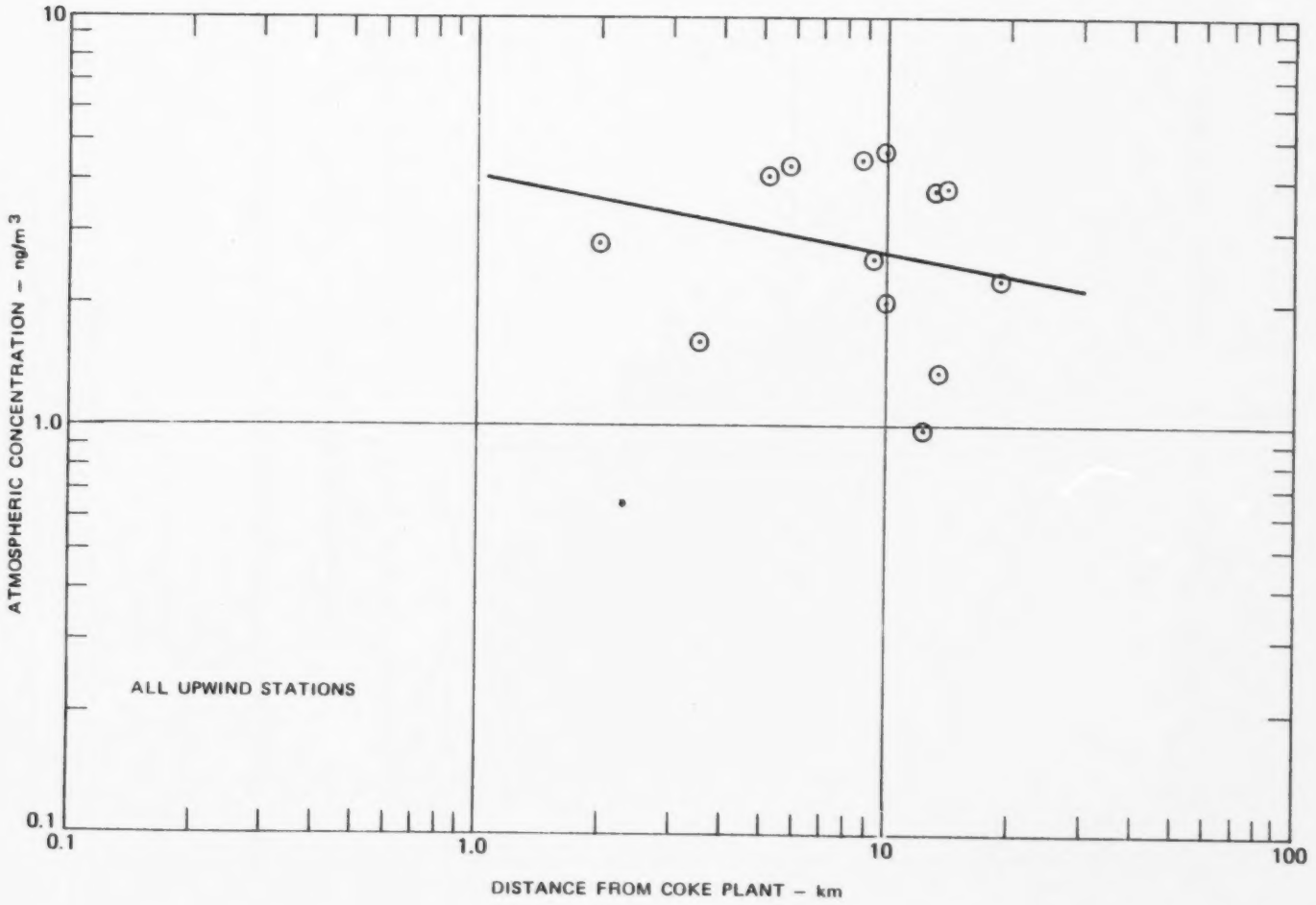


FIGURE B-14. ATMOSPHERIC CONCENTRATIONS OF BaP FOR PHILADELPHIA, PENNSYLVANIA

If ambient data are to be used to characterize human exposure, it would be desirable to have data from many monitoring sites located at different directions from the coke plant and to have data recorded for each monitoring site over a large number of days. Much of the recorded data do not meet these requirements; the number of sampling stations by plant ranged from 1 to 16.

Where elevated concentrations exist, the relationship of average atmospheric concentration to distance does appear to follow a mathematical function of the type:

$$C = aD^b \quad ,$$

where

C = the average concentration at some distance from the coke plant.

a,b = model parameters fit by regression techniques.

D = the distance from the plant.

Least squares regression techniques have been used to fit the data to this mathematical function for each coke plant for which data are available. The results of this evaluation are given in Table B-2. The regression coefficients given in Table B-2 indicate how well the data fit the function. For most cases, the regression coefficients ranged from 0.5 to 1.0, suggesting fairly good approximations. The coke plants with only two monitoring stations do not have sufficient data to perform statistical confidence tests. The model parameters based on actual ambient data can be compared to similar fits to the atmospheric dispersion modeling data conducted by Youngblood (1977). Two conditions are given in Table B-2 for comparison (one for a dirty plant and one for a clean plant).

The magnitude of the model parameter a relates to the amount of BaP emitted from the source, and the model parameter b relates to decay in the concentration versus distance function. Note that for all coke locations with more than two sampling stations on Table B-2 the b parameter varies between -0.32 to -1.42 with an average of -0.9. When locations that have more than one coke plant are also excluded, the parameter has an average value of -1.0. This compares favorably with the modeling data, which give a value of b of about -0.95.

Table B-3 gives statistical tests used to determine if the decay parameter (b) is significantly less than zero. The table shows that in none of the 13 cases is the parameter significantly less than zero at the 0.05 confidence level. For the four cases where significance was not found, the data either were highly variable or there were other coke plants in the area.

Table B-2

ESTIMATED PARAMETER VALUES FOR REGRESSION APPROXIMATIONS TO AMBIENT DATA

Location	Number of Stations	Model Parameters a	Model Parameters b	Regression Coefficient $(R)^2$
Johnstown	8	35.24	-1.13	0.96
Gadsden	2	1.28	-1.62	*
Duluth	2	379.39	-7.50	*
Monessen	3	49.99	-2.92	0.64
Utah	10	4.70	-0.84	0.76
Wayne County	6	13.09	-0.69	0.92
Buffalo--Beth.	5	15.96	-0.99	0.79
Buffalo--D.H.	7	8.40	-0.75	0.60
Buffalo--Allied	4	1.96	-0.33	0.06
Cleveland	16	12.42	-1.42	0.72
Pittsburgh--USS	5	22.00	-0.32	0.16
Pittsburgh--J&L	6	4.32	-0.37	0.52
Tarrant	4	3.98	-0.33	0.75
Granite City	10	11.50	-0.57	0.10
Sparrows Point	4	3.07	-0.33	0.61
Fairfield	2	2.67	-0.07	*
Dirty Plant Model	5	135.84	-0.96	0.99
Clean Plant Model**	4	60.66	-0.95	0.98

*Data available for only two monitoring stations.

**Uses only data for distances of 1 km and greater.

Table B-3

STATISTICAL EVALUATION OF REGRESSION APPROXIMATIONS

Location	$S_{y \cdot x}$	S_b	$t(b < o)$	Significance Level
Johnstown	0.12	0.05	-21.7	0.01
Monessen	1.50	2.71	-1.08	NS
Utah	0.29	0.09	-9.03	0.01
Wayne County	0.04	0.02	-41.2	0.01
Buffalo-Beth.	0.62	0.24	-4.06	0.05
Buffalo--D.H.	0.63	0.22	-3.46	0.01
Buffalo--Allied	1.47	1.13	-0.29	NS
Cleveland	0.14	0.04	-33.02	0.01
Pittsburgh--USS	0.74	0.36	-0.88	NS
Pittsburgh--J&L	0.09	0.05	-7.12	0.01
Tarrant	0.08	0.03	-10.00	0.01
Granite City	1.56	0.75	-0.76	NS
Sparrows Point	0.04	0.04	-8.68	0.01

$S_{y \cdot x}$--Standard error of the estimate in terms of natural logarithms.
S_b--Standard error of the regression slope parameter (b).
$t(b < o)$--Students-t test value for testing if the slope parameter (b) is less than zero.
NS--Not statistically significant at the 0.05 level.

Appendix C

DETAILED ESTIMATES OF POPULATIONS AND BaP CONCENTRATIONS FOR INDIVIDUAL COKE FACILITIES

Appendix C

DETAILED ESTIMATES OF POPULATIONS AND BaP CONCENTRATIONS FOR INDIVIDUAL COKE FACILITIES

This appendix includes the detailed population and BaP concentration estimates for each defined geographic population ring (i.e., 0 to 0.5, 0.5 to 1, 1 to 3, 3 to 7, and 7 to 15 km) about each coke facility. These estimates are given in Tables C-1 and C-2. The concentrations include the summation of atmospheric concentrations from both the coke ovens and background. The population within a geographic ring was considered not to be excessively exposed to coke-oven emissions if its estimated average annual BaP concentration was less than 0.1 ng/m^3. For some locations, several separate coke facilities are located within 15 km of each other. In these cases, it was necessary to estimate geographic population ring overlaps and total ring BaP concentrations.

The exposure estimates given here use the model that assumes variable background concentrations (see Section IV-D).

Table C-1

DETAILED BaP POPULATION EXPOSURES
(Coke Emissions Plus Background)
(ng/m^3)

Site No.*	Distance from Coke Facility (km)									
	0-0.5		0.5-1		1-3		3-7		7-15	
	Population	Concentration	Population	Concentration	Population	Concentration	Population	Concentration	Population	Concentration
1	388	F	1,756	F	13,880	F	114,873	F	278,354	F
2	0	1.5	0	0.9	0	0.6	5,843	--	7,802	--
3	0	15.0	0	8.2	21,495	3.3	80,440	1.6	196,316	0.9
4	478	6.0	916	2.0	19,693	--	36,345	--	21,099	--
5	1,656	1.7	532	1.1	36,497	0.7	158,506	--	283,180	--
6	975	F	5,279	F	28,195	F	120,414	F	297,002	F
7	0	5.0	0	4.2	22,105	3.1	120,356	2.4	256,857	F
8	0	19.0	1,416	10.0	9,493	4.5	51,629	2.5	161,178	1.8
9	0	10.0	0	5.6	0	2.5	0	1.4	52	0.9
10	0	2.0	2,244	1.4	30,475	--	46,890	--	704,796	--
11	827	7.3	7,307	4.2	58,244	2.0	248,247	1.2	1,153,057	--
12	0	19.0	0	10.0	0	4.3	2,828	2.2	14,649	--
13	2,618	4.8	2,494	2.9	27,666	1.4	187,310	--	1,223,577	--
14	0	19.0	0	11.0	0	4.4	16,253	2.2	73,329	1.4
15	57	5.4	8,176	3.2	71,661	1.7	207,269	1.1	444,465	0.9
16	512	2.1	3,059	1.5	36,083	1.0	42,851	--	24,392	--
17-18**	0	87.0	53	47.0	21,279	18.0	51,533	7.6	520,919	3.9
19	0	68.0	33	37.0	26,829	14.0	122,882	6.1	265,439	3.2
20	99	39.0	482	21.0	25,740	8.4	70,004	3.8	637,625	2.1
21	552	30.0	0	16.0	15,511	6.2	35,072	2.7	90,904	1.5
22	11	4.3	3,416	3.5	15,948	2.5	97,933	1.9	481,929	--
23	0	F	3,008	F	37,283	F	289,066	F	1,190,455	F
24	0	F	2,197	F	46,224	F	322,403	F	1,274,124	F
25	0	F	51	F	33,878	F	172,788	F	892,126	F
26	991	2.2	3,901	1.3	61,720	0.8	255,071	--	727,327	--
27	0	4.2	0	2.0	4,219	0.8	7,036	--	76,894	--
28	3,368	3.9	2,450	2.0	30,734	0.9	224,719	0.6	714,782	--
29	0	2.7	202	2.1	7,874	1.6	111,218	1.2	601,056	--
30	0	F	3,113	F	17,140	F	138,521	F	531,748	F
31	1,184	F	2,537	F	58,527	F	257,202	F	533,320	F
32	0	23.0	2,373	13.0	11,701	5.1	55,346	2.4	37,066	1.4
33	6	18.0	2,608	9.7	8,567	3.7	57,955	2.0	83,131	1.2
34	0	14.0	0	7.9	455	3.3	749	1.7	17,189	1.1

Table C-1 (Concluded)

Site No.*	Distance from Coke Facility (km)									
	0-0.5		0.5-1		1-3		3-7		7-15	
	Population	Concentration	Population	Concentration	Population	Concentration	Population	Concentration	Population	Concentration
35	0	2.1	0	1.4	10,963	0.9	30,503	--	50,851	--
36	0	12.0	0	6.4	5,352	2.8	34,067	1.5	24,213	1.0
37	663	8.4	1,597	4.7	22,961	2.0	155,445	1.0	258,780	0.7
38	1,530	42.0	4,228	25.0	73,580	4.5	399,565	2.3	859,264	--
39	0	2.4	71	1.5	17,663	1.0	40,897	--	152,877	--
40	0	13.0	0	6.9	20,260	3.0	82,028	1.6	96,129	1.0
41	0	11.0	1,986	6.4	45,234	2.9	147,771	1.6	133,429	1.2
42	13	20.0	2,858	11.0	72,578	4.4	378,615	2.1	860,216	1.3
43	0	18.0	4,074	9.2	33,723	3.8	115,698	1.9	164,425	1.2
44	0	6.4	0	3.8	26,142	1.9	110,829	1.3	734,938	1.0
45	3,960	16.0	1,593	9.1	42,961	3.9	64,472	2.0	229,293	1.4
46-47**	1,804	100.0	870	50.0	35,460	17.0	51,502	5.2	38,180	2.2
48	0	5.4	0	3.3	573	1.7	12,276	1.2	91,115	1.0
49	0	16.0	0	9.2	19,922	4.0	61,371	2.1	116,901	1.4
50	0	F	10,170	F	115,372	F	396,226	F	748,696	F
51	2,628	2.8	10,041	1.9	56,243	1.2	87,797	1.0	40,701	--
52	2,433	14.0	4,526	7.8	54,405	3.4	486,896	1.8	1,685,267	1.3
53	0	F	75	F	31,991	F	122,412	F	632,088	F
54	1,024	F	1,365	F	16,819	F	83,779	F	407,475	F
55	2,374	34.0	1,757	18.0	30,671	7.4	117,606	3.4	354,575	2.0
56	0	50.0	1,559	38.0	22,763	10.0	42,498	2.0	80,359	--
57	1,185	1.8	5,483	1.2	16,595	0.7	81,104	--	117,888	--
58	6	11.0	0	5.7	4,866	2.1	99,968	0.9	350,402	0.4
59	0	3.5	0	1.9	1,046	1.0	2,219	0.3	8,902	--
60	19	10.0	0	5.8	3,044	2.6	28,887	1.2	72,123	--
61-62**	0	79.0	0	43.0	0	16.0	3,570	6.9	8,598	3.4
63	0	6.0	0	3.4	0	1.6	0	0.9	1,410	0.7
64	3	18.0	0	9.8	20,971	4.0	39,901	1.9	65,031	1.1
65	1,300	3.1	4,100	2.0	43,000	1.2	219,000	0.9	NE	--

*Site numbers correspond to coke facilities listed in Table III-3.

**Indicates that the two facilities were treated as though they were collocated.

F Indicates that one or more coke facilities are located within 15 km of that facility. Estimated concentrations are given in Table C-2.

-- Indicates that the atmospheric BaP concentration due to the coke facility was less than 0.1 ng/m^3.

Table C-2

BaP EXPOSURES FOR PERSONS IN LOCATIONS HAVING MORE THAN ONE COKE FACILITY

Location	Exposed Population	Exposure Concentration (ng/m^3)
Birmingham, Alabama	975	8.2
	388	5.8
	14,025	5.6
	7,035	4.5
	28,054	3.0
	110,000	2.6
	135,893	1.6
Detroit, Michigan	51	12.0
	5,000	8.1
	2,197	7.8
	41,000	6.7
	3,008	4.5
	19,900	4.0
	330,000	3.6
	14,913	3.4
	1,274,124	2.1
Buffalo, New York	3,113	22.0
	1,184	17.0
	19,000	12.0
	2,537	10.0
	11,300	8.0
	39,000	5.0
	533,000	1.6
Pittsburgh, Pennsylvania	1,024	30.0
	1,365	24.0
	83,800	13.0
	407,500	10.0
	10,170	4.8
	147,363	3.0
	396,226	2.0
	16,819	1.8

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